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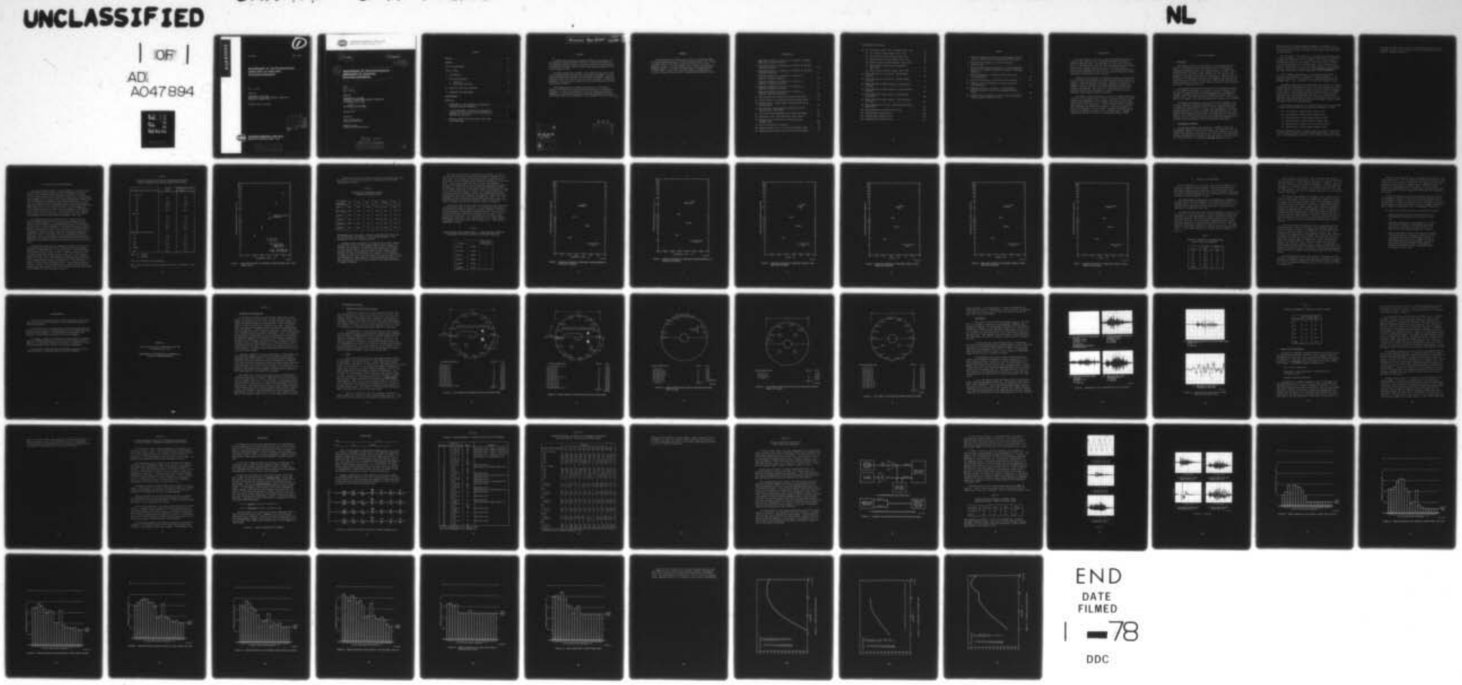

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Final Report January 1975

MEASUREMENT OF THE PSYCHOLOGICAL ANNOYANCE OF SIMULATED EXPLOSION SEQUENCES

By: J. R. YOUNG

Prepared for:

DEPARTMENT OF THE ARMY
CONSTRUCTION ENGINEERING RESEARCH LABORATORY
CHAMPAIGN, ILLINOIS 61820

CONTRACT DACA 23-74-C-0008

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SRI Project 3160

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ABSTRACT

An explosion and explosion-sequence simulator was developed in the laboratories of Stanford Research Institute in Menlo Park, California. The simulator produces vibrations and sounds similar to those that would be experienced by people inside a typical frame dwelling located 1-3 km from an explosion site.

Ten adult subjects were exposed to the sounds and vibrations caused by six different simulated explosions and explosion sequences. The concomitant psychological annoyance was measured by the method of magnitude estimation with a jet aircraft noise as a scalar reference. Six physical measures of the noises were obtained and were used to correlate with the psychological measures.

Total energy measures, weighted spectrally by D1- and D2-type weights, were found to be the best physical predictors of psychological annoyance. In this pilot experiment it was also found that annoyance judgements of simulated explosions and explosion sequences were probably less reliable than similar judgements of the annoyance of aircraft noises.

FOREWORD

This research was performed under Contract No. DACA23-74-C-0008. The authorized Representative of the Contracting Officer was Mr. Richard G. Donaghy, Chief, Environment and Energy Systems Division, CERL, Champaign, Illinois. Dr. Paul Schomer, also of CERL, was the Contract Technical Monitor. The research was performed at Stanford Research Institute (SRI) in Menlo Park, California under the supervision of Dr. Karl D. Kryter, Director of SRI's Sensory Sciences Research Center.

ILLUSTRATIONS

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I INTRODUCTION

This final report on Contract No. DACA 23-74-C-0008 describes the results of the research effort to measure psychological annoyance caused by impulsive noise. The motivation for this work arises from the U.S. Army engineering activities and training exercises that require detonation of explosive charges or firing of artillery weapons in certain areas throughout the United States. The resultant noise sometimes reaches populated civilian areas and may cause community annoyance and negative social and political reactions.

A planned two-part program of laboratory research is being carried out to develop data and methods for predicting psychological annoyance caused by single and multiple explosions. During the first part of the program, a facility capable of simulating explosions and explosion sequence sounds was developed and a pilot experiment using ten adult subjects was conducted. The second part of the program will be an extensive study of physical measures of impulsive noise for use in accurately predicting psychological annoyance.

This report, covering the research activities completed during the first part of the program, deals primarily with the results of a psychological pilot experiment and the findings coming out of correlations between physical measures of noise stimuli and psychological responses from subjects in the experiment. An Interim Report, written in August 1974, described the simulator development; it has been abridged for inclusion as Appendix A in this report. Appendix B describes the raw data and the procedural details of the pilot experiment. Appendix C presents the details of the physical measurement analysis system.

II THE PILOT EXPERIMENT

A. Objectives

One objective of the pilot experiment was to determine the suitability of the simulation facility for measuring the psychological annoyance of impulsive noises. The simulator used is a mechanically operated plunger that drives into a pneumatic plenum, one side of which is the wall of a test room in which subjects sit. The motion of the plunger is controlled by the shape of a rotating cam. The cam shape and the speed of the cam rotation determine the pneumatic pressures and wall motions that are produced in the test room. These motions simulate the motions measured in a typical frame structure exposed to actual explosions occurring at a distance of 1-3 km.

Our preliminary work during the first half of the project resulted in six acceptable cam designs. To conduct a practical experiment, all six cams were needed and were mounted and demounted in a pseudorandom sequence. Because mounting one cam and demounting another requires several minutes, the effect that these delays may have on a major experiment was one aspect of the facility operation that needed to be evaluated.

The second, more important objective of the pilot experiment, was to make preliminary psychological measurements of the annoyance caused by sounds that were reasonably similar to actual sounds of explosions and explosion sequences and to correlate these measurements with simple physical measures of the noises. Before the experiment was run, we had neither firm estimates of the annoyance associated with the noises produced by the six cams selected for use in the experiment nor the relative estimates for the annoyance caused by these noises when compared with aircraft flyover noises used in previous laboratory experiments.

B. Experimental Procedure

The ten adult subjects were exposed to a sequence of 38 noises. The sequence included 6 simulated explosions, each presented twice, and 10 different aircraft flyover noises. The aircraft noises were a B 747 takeoff noise presented at maximum levels of 50, 60, 70, 80, and 90 dB(A) and a DC 8 landing noise presented at the same levels. The B 747 noise at 70 dB(A) was used as a designated <u>reference noise</u> and actually

occurred 17 times scattered randomly throughout the sequence. All other aircraft noises were presented only once. Thus, the presentation of the experimental stimuli consisted of 12 simulated explosions and 26 aircraft flyovers.

The task given to the subjects was to estimate the annoyance value, or objectionableness, of the various noises heard during the experiment. The measure of annoyance was to be marked on ratio scales printed on response sheets given to each subject. The ratio scale was "anchored" by using the reference noise mentioned above. This reference noise, given an assigned value of 10, was presented frequently in the stimulus sequence. This method of measurement, called magnitude estimation, has been used successfully in earlier experiments in our laboratory.

A more complete understanding of the magnitude estimate (ME) technique can be obtained, if necessary, by reading Appendix B. The general instructions to the subjects and a sample response sheet are included there. Also, a complete list of the noise sequence is given.

The subjects participated in experimental sessions that ran without interruption for approximately one hour. The noise sequence was pseudo-random, adjusted to intersperse aircraft noises and simulated explosions so that time for cam changes overlapped the presentation of a recorded aircraft noise. The presentation of the stimuli was rehearsed several times before the actual experiments were run so as to ensure that a reasonably short time could be achieved in presenting all 38 noises and that long, awkward delays during simulator cam changes would not destroy the basic continuity of the experiment.

The six cams selected for use in the pilot experiment were designed to produce simulated explosions or explosion sequences as follows:

(1) Low-intensity, single-impact explosion (LIS)

(2) Low-intensity, multiple-impact sequence (LIM)

(3) Medium-intensity, single-impact explosion (MIS)

(4) Medium-intensity, multiple-impact sequence (MIM)

(5) High-intensity, single-offset noise pulse (HISOS)

(6) High-intensity, multiple-impact sequence (HIM)

With the exception of HISOS, all these noises are realistic simulations of explosions or groups of explosions heard indoors under field conditions. The HISOS noise, however, is not a realistic simulation; rather,

it sounds more like a door slam than a distant explosion heard indoors. Waveforms of these noises as observed with a microphone and an oscilloscope are included in Appendix C.

III RESULTS OF THE PILOT EXPERIMENT

The MEs of annoyance given by the ten subjects in the pilot experiment were pooled and are listed, by stimulus presented, in Table 1. In this table, the psychological data were averaged for each noise, and the standard deviation was calculated for each noise. Ten responses were averaged for all of the aircraft noises (except the reference noise) and 20 responses were averaged for the simulated explosions. By intention, the estimates of annoyance caused by the aircraft noise almost completely span the range of annoyance caused by the simulated explosions. These ranges are 3.4 to 54.0 and 2.8 to 22.9. On the average, the worst aircraft noise was more than twice as annoying, or objectionable, as the worst simulator noise, HIM. At the other end of the annoyance range, however, the low-intensity aircraft noises were only slightly more annoying than the lowest-intensity simulator noise, LIS.

The standard deviations obtained from the pooled data seem to differ systematically between the aircraft noise responses and the simulator noise responses. The standard deviations of the responses to aircraft noise are about 48 percent of the mean values on the average; the same ratio is about 82 percent for responses to simulated explosions. There is an implication, and it seems to be borne out by the raw data in Appendix B, that our subjects were more reliable and consistent in judging the aircraft noises than they were in judging the simulated explosions. That is, intersubject and intrasubject variabilities are greater when the subjects give MEs of annoyance caused by the simulated explosions than when they estimate the annoyance of the various aircraft noises.

The physical measure used to describe the aircraft noises was the A-weighted maximum sound level meter reading with the meter movement adjusted to the SLOW response. As shown in Table 1, the maximum levels read correlate very well with the MEs of annoyance. The data plotted in Figure 1 demonstrate by their rather linear array on the semilogarithmic paper that the average subjective response follows the general pattern of a ratio scale. This conclusion is strongly supported by the Pearson product-moment correlation coefficient, r, that has values in excess of 0.99 for both B 747 and DC 8 data. These values measure the tendency of the data to be representable by a linear function and are significant at the 1 percent level. The 70 dB(A) levels equal 86.5 EPNdB and 84.7 EPNdB for the B 747 and DC 8 noises.

Table 1

SUBJECTIVE MAGNITUDE ESTIMATES OF PSYCHOLOGICAL ANNOYANCE CAUSED BY AIRCRAFT NOISE AND SIMULATED ARTILLERY NOISE

Recorded Aircraft Noise, dB(A)	Average ME*	Standard Deviation, σ, of ME
B 747 TO		
50	3.4	1.9
60	6.0	3.4
70	10.0†	0.0†
80	25.0	14.1
90	43.0	19.5
DC 8 L		
50	3.5	1.8
60	5.3	1.6
70	13.7	5.6
80	29.0	13.7
90	54.0	24.6
Simulated Artillery Noise		
LIS	2.8	2.2
LIM	10.6	9.4
MIS	21.4	17.3
MIM	21.5	20.5
HISOS	6.0	4.5
HIM	22.9	17.5

Note: TO = takeoff
L = landing

*Data were obtained from ten subjects.

†This noise was used as the ME reference noise that was assigned a value of 10.

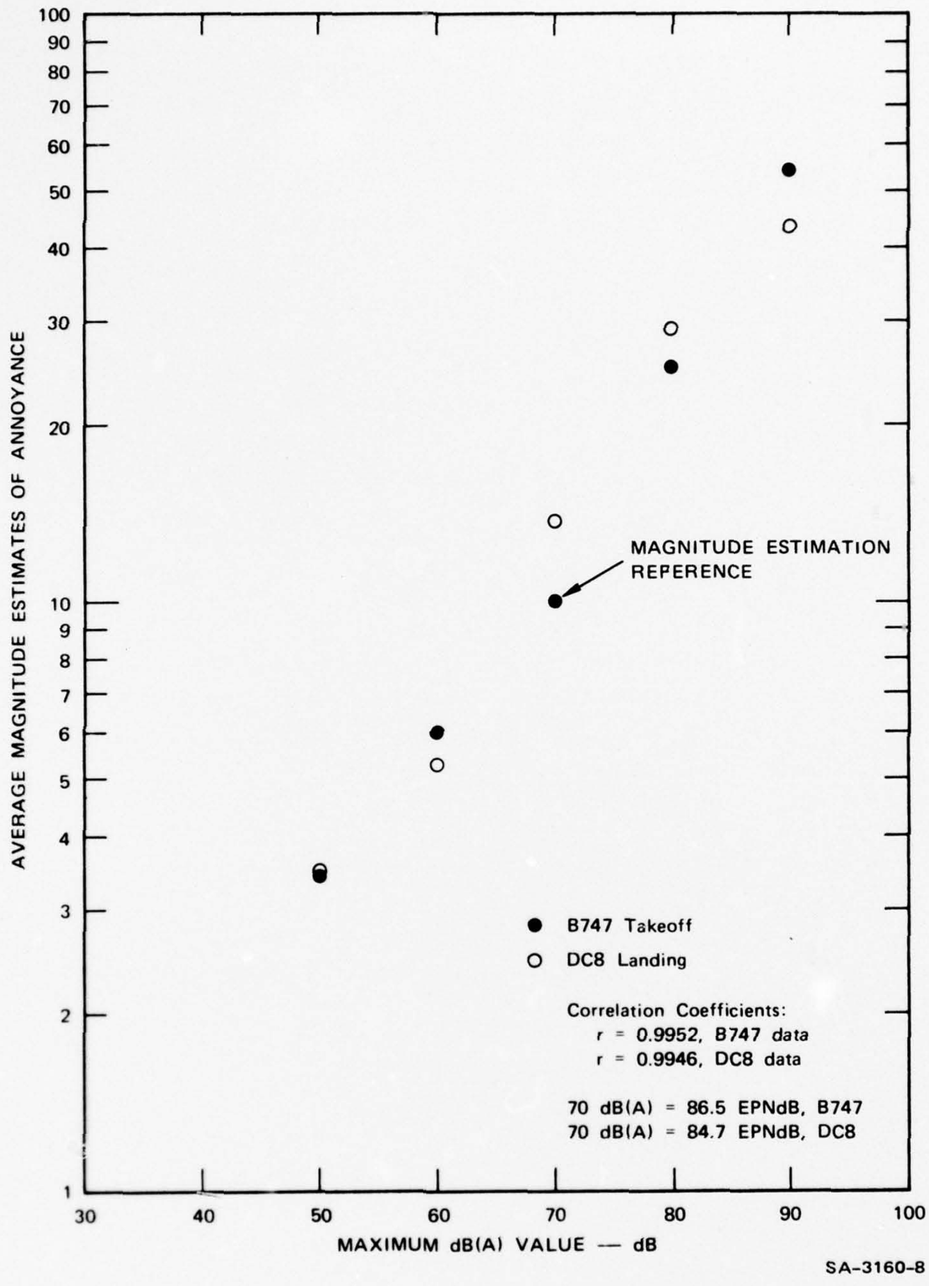


FIGURE 1 MAGNITUDES ESTIMATES OF ANNOYANCE VERSUS MAXIMUM dB(A) LEVELS: AIRCRAFT NOISE

Six physical measures were used to describe the simulated explosions. The names and values of these measures as obtained from the various noises appear in Table 2.

Table 2

PHYSICAL NOISE MEASURES OF STIMULI
GENERATED BY SIMULATOR CAMS

Cam / Measure	LIS	LIM	MIS	MIM	HISOS	HIM
max SPL	90.0	95.5	106.0	107.0	112.5	109.5
max dB(A)	55.0	57.2	73.2	70.0	70.0	77.0
Σ_e dB(A)	24.0	35.6	47.1	47.1	44.1	51.7
Σ_e dB(D1)	40.4	51.2	58.7	58.9	55.5	63.3
Σ_e dB(D2)	34.0	44.4	53.4	54.3	50.9	58.7
Σ_e dB(OA)	55.7	66.5	73.7	73.0	72.8	79.0

The measures are of two types: measures of maximum noise levels [max SPL and max dB(A)] and measures of total energy weighted, or not, according to the noise frequency spectrum.

Maximum values are obtained by passing the noise signal through a metering circuit with the SLOW dynamic response and by reading the maximum level reached at any time during the presence of the signal. To obtain max SPL values, the noise signal was unfiltered; to obtain max dB(A) values, the A-weighting filter was used. Oscillographic tracings were used to record meter-like responses; as an alternative to using an actual meter, the table values were read from these tracings. This procedure was used because the simulated explosion signals are short and produce rapidly varying and hard-to-read needle movements on a standard instrument.

The total energy measures, prefaced by the notation Σ_e, have not previously been used in predicting psychological response to noise. These values are obtained by calculating the total energy present in specified 1/3-octave frequency bands during the occurrence of a particular noise. The 1/3-octave bands used here span the range 10-500 Hz. Details of the measurement system and the analysis procedure are given in Appendix C, along with the actual spectral measurements obtained. The 1/3-octave band values (total energy values) were weighted in various ways to get the values shown in Table 2. The notation OA means that the values were uniformly weighted, A means that A-weighting was applied, D1 and D2 mean that those weightings were applied. Because our analysis included 1/3-octave bands below those normally used, the A-, D1-, and D2-weightings were extrapolated beyond the standard low-frequency limits. Tables and graphs showing these weightings appear in Appendix C.

The physical measures and the MEs of annoyance have been correlated with the results shown in Figures 2-7. The correlation coefficient, r, is printed in each figure to indicate the linear tendency in the relationship between the psychological and physical data. Two correlations, max SPL and max dB(A) with MEs of annoyance, are too small to be of significance in our work. All four correlations with total energy measures are significant at the 5 percent level; two of them [Σ_e dB(D1) and Σ_e dB(D2)] are significant at the 1 percent level. These data are summarized in Table 3.

Table 3

PEARSON PRODUCT-MOMENT CORRELATIONS, r, BETWEEN MAGNITUDE ESTIMATES OF ANNOYANCE AND PHYSICAL MEASURES OF SIMULATED EXPLOSIONS

Measure	r	Significance (percent)
max SPL	0.5774	- %
max dB(A)	0.7479	-
Σ_e dB(A)	0.8641	5
Σ_e dB(D1)	0.8977	1
Σ_e dB(D2)	0.8747	1
Σ_e dB(OA)	0.8377	5

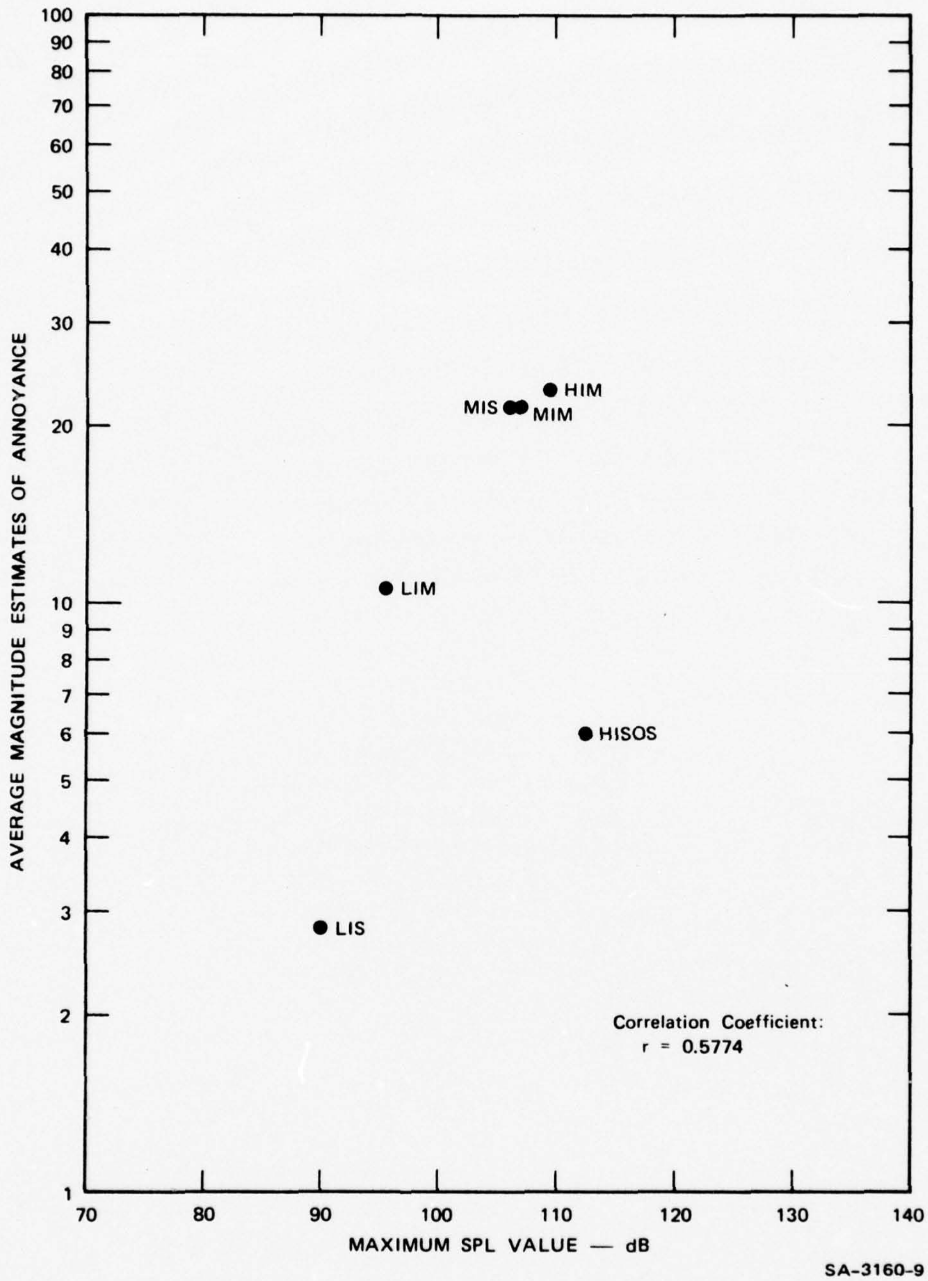


FIGURE 2 MAGNITUDE ESTIMATES OF ANNOYANCE VERSUS MAXIMUM SPL: SIMULATED EXPLOSIONS

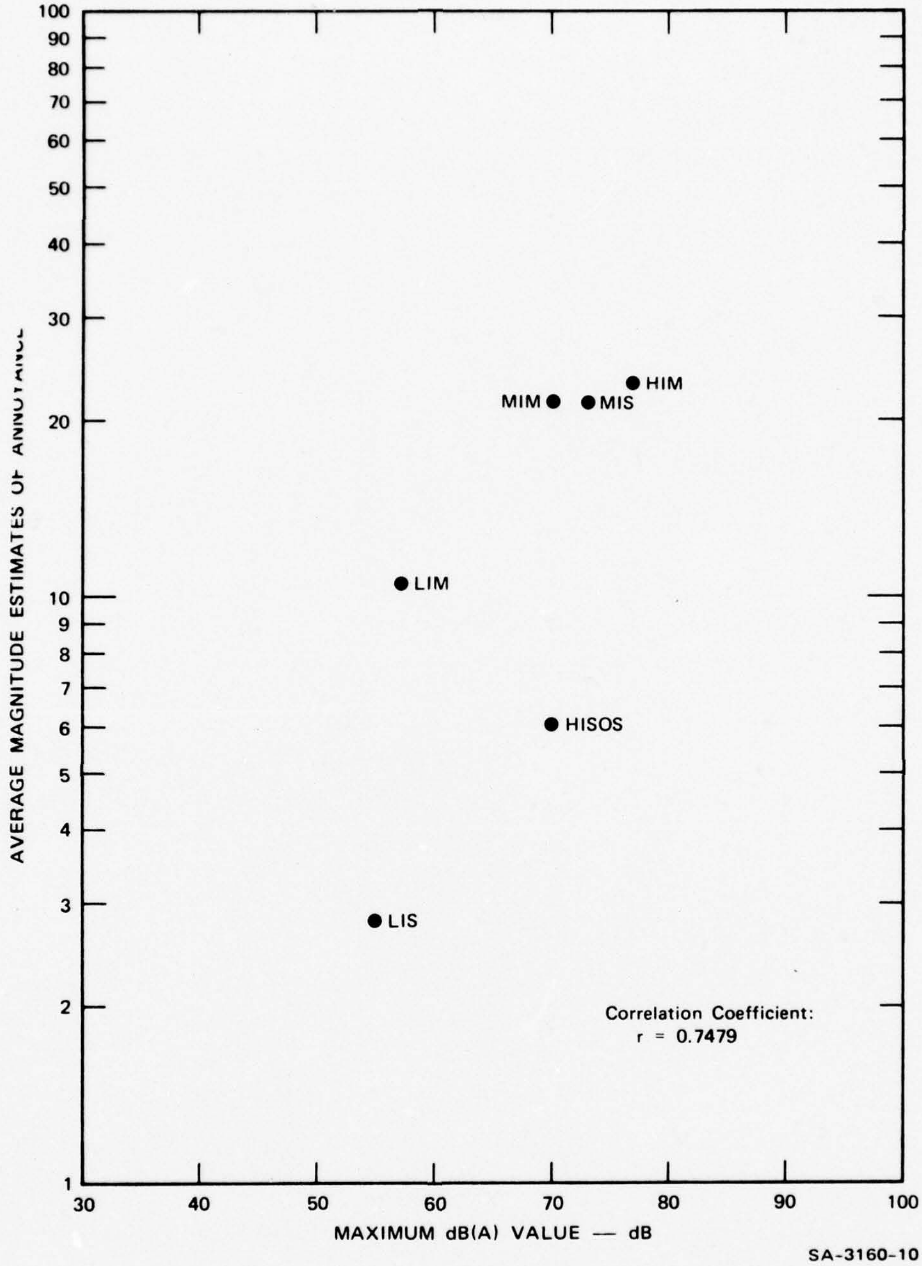


FIGURE 3 MAGNITUDE ESTIMATES OF ANNOYANCE VERSUS MAXIMUM dB(A): SIMULATED EXPLOSIONS

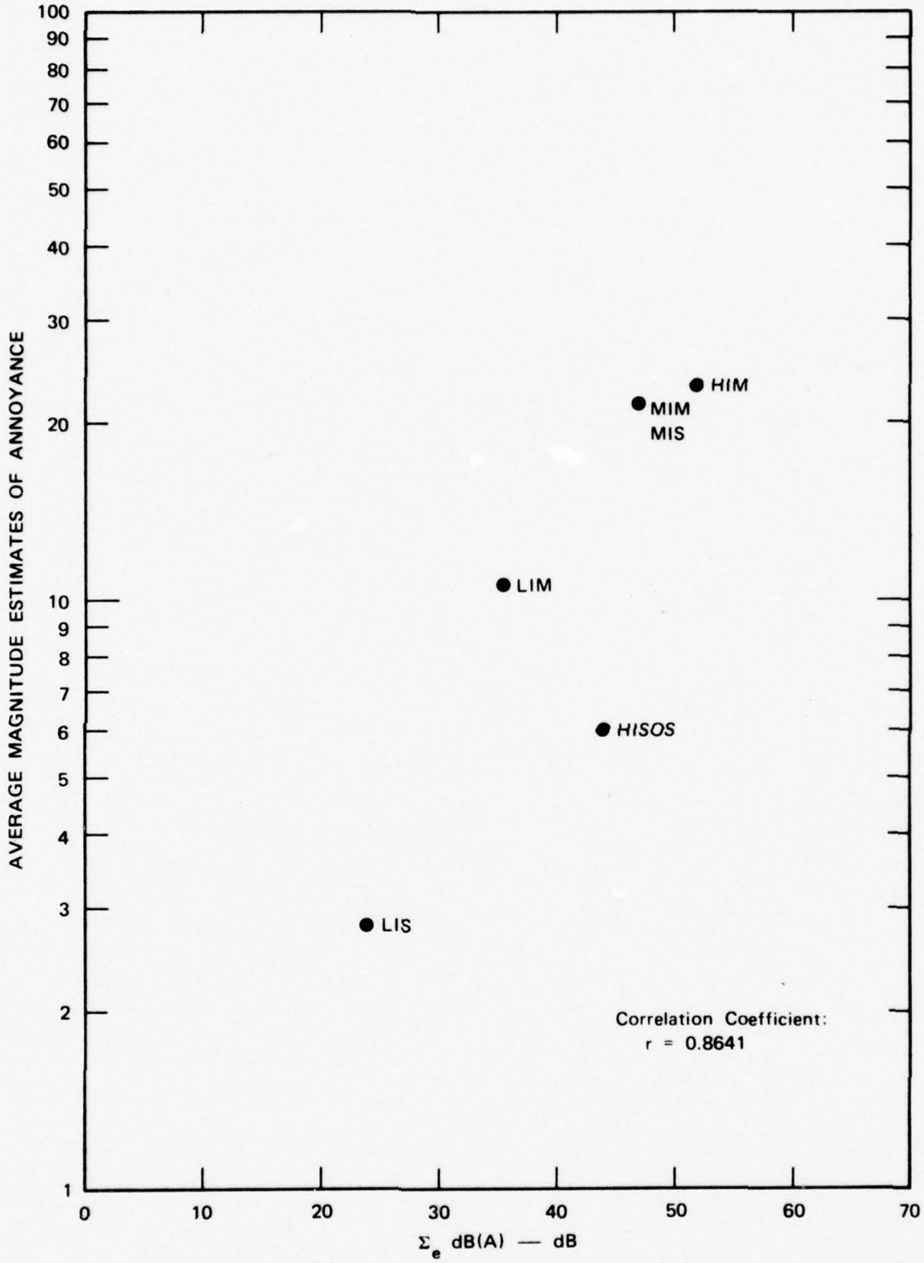


FIGURE 4 MAGNITUDE ESTIMATES OF ANNOYANCE VERSUS Σ_e dB(A): SIMULATED EXPLOSIONS

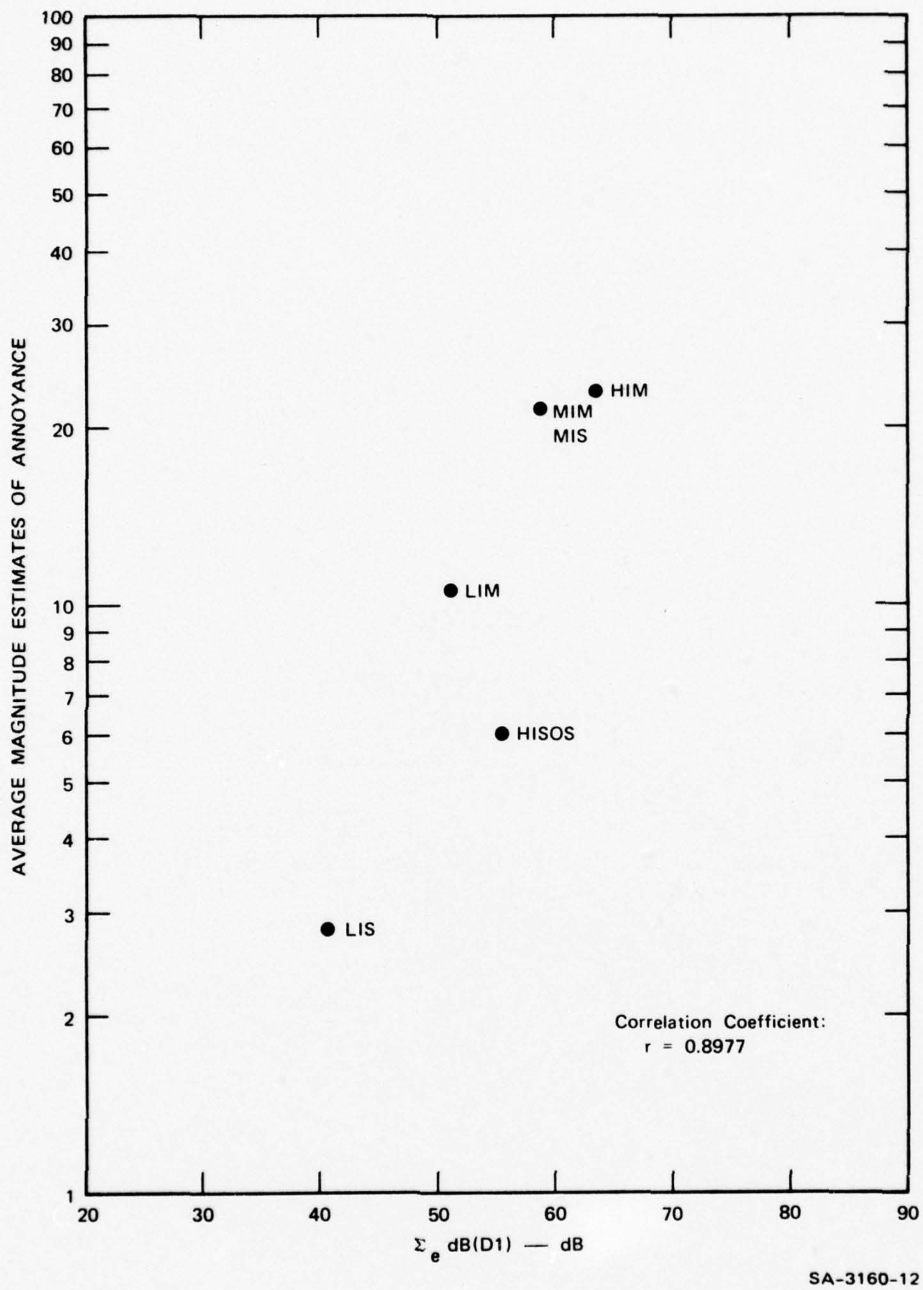


FIGURE 5 MAGNITUDE ESTIMATES OF ANNOYANCE VERSUS Σ_e dB(D1): SIMULATED EXPLOSIONS

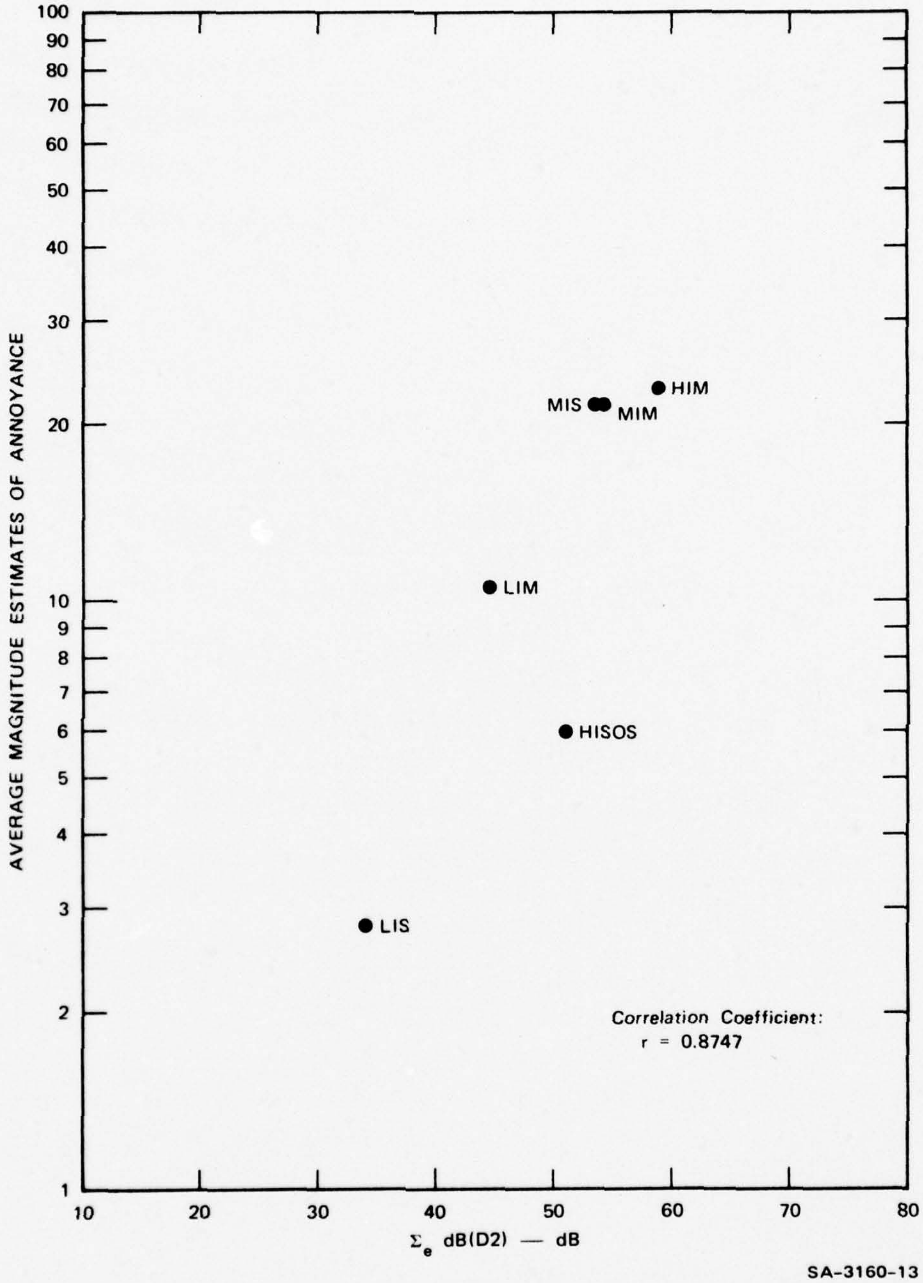


FIGURE 6 MAGNITUDE ESTIMATES OF ANNOYANCE VERSUS Σ_e dB(D2): SIMULATED EXPLOSIONS

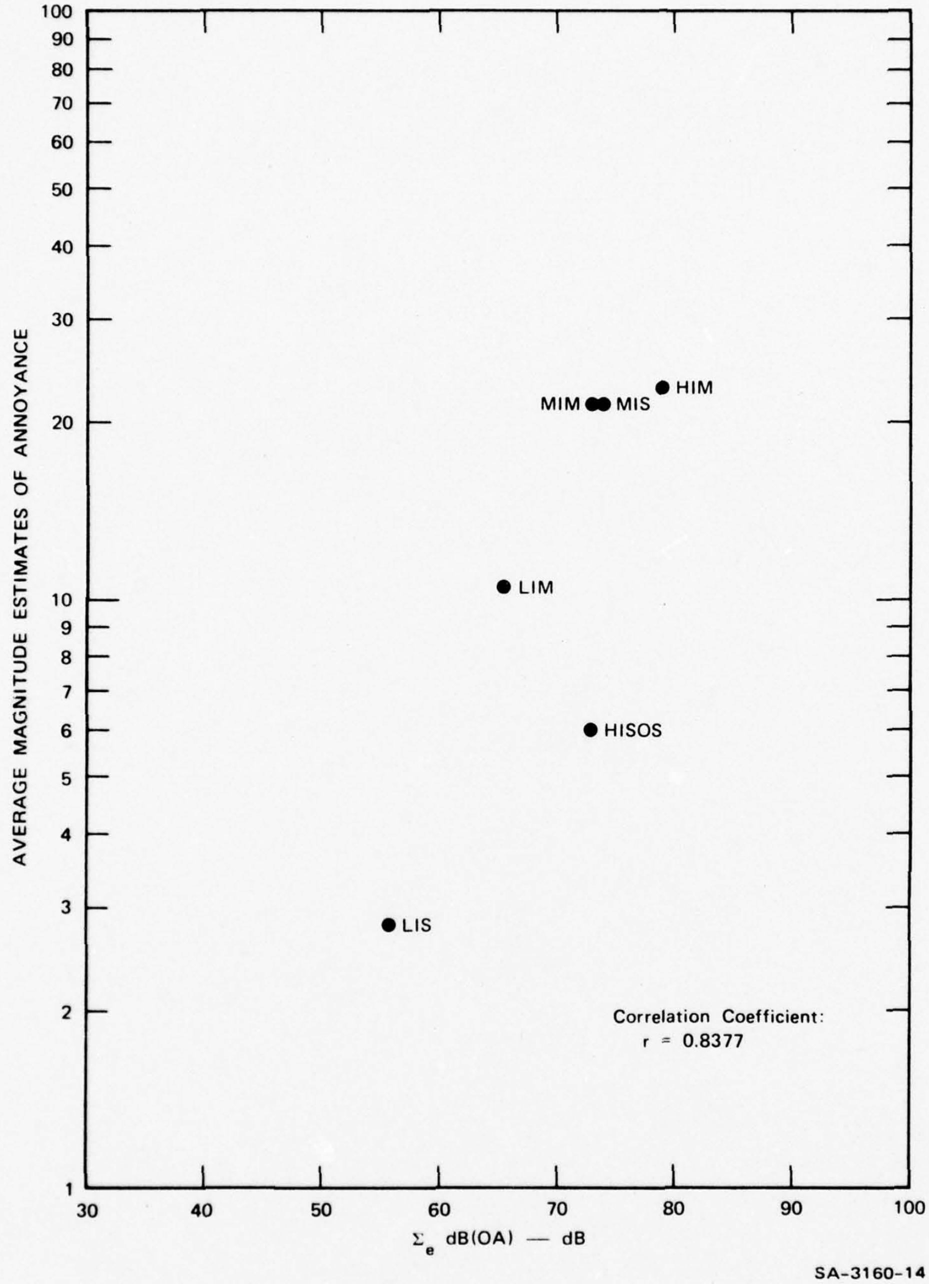


FIGURE 7 MAGNITUDE ESTIMATES OF ANNOYANCE VERSUS Σ_e dB(OA): SIMULATED EXPLOSIONS

IV DISCUSSION AND CONCLUSIONS

The accomplishments of this year's work are the development of an impulsive or explosive noise simulation facility and the use of that facility in running a pilot experiment. The simulator design and development occupied about one-half of the effort expended. The remaining effort was used in running the pilot experiment and in accomplishing the physical and psychological analyses.

The Interim Report, included here in abridged form as Appendix A, discusses the design and development of the simulation facility in considerable detail. We feel, however, that a brief discussion of a few important points regarding the noises selected for use in the pilot experiment is worthwhile at this time.

Six explosion-like noises were used as experimental stimuli for our ten subjects. Of these six noises, five were intended to be realistic simulations of single and multiple artillery shell impact sounds; one noise was created by activating the simulator plunger with a single cam offset of 10 mm. The five realistic simulations varied in both intensity and duration; the intensities ranged from 90.0 to 109.5 dB (max SPL), and durations ranged from about 0.3 s to 4.0 s. The single offset cam noise had an intensity of 112.5 dB (max SPL) and a duration of 1.7 s. The actual values for all of these noises are shown in Table 4.

Table 4

PHYSICAL PARAMETERS OF SIMULATOR NOISES
USED IN THE PILOT EXPERIMENT

Noise	max SPL (dB)	Duration (s)
LIS	90.0	0.3
LIM	95.5	3.0
MIS	106.0	1.0
MIM	107.0	4.0
HIM	109.5	0.4
HISOS	112.5	1.7

In our opinion, the realistic noises were quite good simulations of actual noises that we had heard in the field. The LIS and MIS noises had the percept of a single explosion followed by a "rumble," while the LIM, MIM, and HIM noises all carried the percept of multiple explosions occurring in a short time interval. The HISOS noise was distinct from the other noises; it had a percept more similar to that of a door slam or a bump against a wall than to a distant explosion; it was a relatively intense, short sound.

The simulator cam assembly was arranged so that a change from one sound to another could be made in a minimum time of about 2.5 minutes. This was a constraint in the design of the pilot experiment; we tried to present all of the experimental stimuli in a pseudorandom sequence of aircraft noises and simulator noises, but we adjusted the original sequence obtained from a random number table to eliminate sequences of consecutive simulator noises. This adjustment (often accomplished by interjecting the reference noise) reduced the average waiting time between successive stimuli because a cam change could be done while an aircraft noise was being presented. We have not analyzed the data for possible sequential effects of this design constraint, but we believe that any effects that may exist must be small and probably inconsequential.

The data from the pilot experiment show (as expected) that the annoyance values of the aircraft noises can be predicted quite well with the max dB(A) measures. No measures that we used, however, predicted the annoyance values of the simulator noises as well. The relatively poor performance of these measures is mainly their inability to predict the annoyance value of HISOS. This can be seen in any of the Figures 2-7 where the "outlying" point is always that related to HISOS. One might be tempted to ignore this fact on the basis that HISOS is not "realistic" and is therefore of much less "practical" interest than the other simulator noises. Still, it would seem that a better physical measure could be devised to handle this particular case, especially since the values of the physical variables describing HISOS actually differ only slightly from those describing the other simulator noises.

The psychological data also show that MEs of annoyance are more reliable, or repeatable, and are more consistent from subject-to-subject when aircraft noises are judged than when simulator noises are judged. We have not established the reasons for this, but we can offer at least two speculations.

Perhaps the simulated explosions are inherently less neutral sounds than aircraft noises. That is, people are much less indifferent to the sounds of more-or-less distant explosions; the range of emotional impact generated by these sounds is greater than that generated by the more familiar and well-understood aircraft sounds. Were this lack of neutrality a psychological fact, it would tend to correlate positively with intersubject variability though not necessarily with intrasubject variability.

Perhaps the shortness of our pilot experiment and the limitation of the number of times a simulator noise was presented had an effect on intrasubject variability. Were this lack of training a factor, it would result in a negative correlation between intrasubject variability and the number of trials during which a noise was judged, but would not have a necessarily measurable impact on intersubject variability.

On the basis of this year's work, we conclude the following:

- Single and multiple artillery impact explosions can be simulated realistically in our laboratory facilities.

- Subjective experiments can be conducted in our laboratory facility, subject to some sequence and timing constraints. The effects of these constraints are unknown, but are assumed (and appear) to be small.

- Physical measurements based on the spectrally weighted total energy content of simulator noises can be used to predict quite well the psychological annoyance associated with a given noise. However, the correlation between physical and psychological measures is poorer than that obtained with a simple physical measure (max dB(A)) and the MEs of annoyance caused by ordinary aircraft noise.

ACKNOWLEDGMENTS

Dr. Karl D. Kryter gave general technical direction to the project team and was specifically responsible for the design and execution of the pilot experiment.

Mr. James E. Davis was responsible for obtaining acoustic measurements and for calibrating and arranging electronic instrumentation used during the entire project. He participated in the collection and analysis of the field data obtained at Fort Sill, Oklahoma.

Mr. Donald J. Peeler was responsible for fabricating the simulator cams, for subsequent modifications of them, and for running the pilot experiment. He analyzed acoustic data related to the simulator facility and the psychological data obtained from the pilot experiment.

Miss Mary Ellen Dobbs prepared the experiment instructions forms, recruited subjects, and helped conduct the pilot experiment.

Appendix A

Interim Technical Report Submitted August 1974
Abridged December 1974:

MEASUREMENT OF THE PSYCHOLOGICAL ANNOYANCE OF
SIMULATED EXPLOSION SEQUENCES

Appendix A

1. Introduction and Background

In the course of normal training and other operations at posts within the continental United States, the Army explodes various sized charges of high explosives and fires artillery and rocket weapons on ranges specifically designed for these purposes. While the principal effects of these activities are confined to the ranges, sounds and noises generated often propagate beyond the range area and beyond the limits of Army posts. These noises may constitute a significant negative environmental impact on adjacent communities. This research project, whose interim status is described in this report, has as its objective the measurement of psychological annoyance expected to be experienced in communities exposed to the sounds or noises produced by sequences of explosions of fixed charges of high explosives, or muzzle blasts from artillery pieces, or impact explosions of artillery shells or rockets. In typical situations these sequences may be as simple and short as a single explosion, but they may also consist of many explosions (as from a large battery of artillery pieces) that cause more or less continuous roars for several seconds.

Laboratory simulation of typical range noises as heard indoors and human subjective judgment tests have been selected as the means of measuring psychological annoyance. The project has been divided into two phases, the first largely concerned with producing an acceptable laboratory simulation of various artillery and rocket noises; this phase is now underway. The second phase of the work will be dedicated to using the simulation facility to expose subjects to the noises with the subjects being asked to render judgments of psychological annoyance as the various types of actual sounds are simulated.

This report deals with the first phase work on the production of acceptable simulations of artillery range sounds that were observed on 1 and 2 November, 1973 at Fort Sill, Oklahoma. On those days, measurements were made on the Post in a frame building located approximately three km from the firing lines and impact area used during a fire power demonstration. Accelerometers were used to measure building movements, and microphones were used to measure acoustic signals present inside an office in the building. These measurements were then used to guide experimenters using our simulation facility as they attempted to reproduce in the laboratory sounds similar to those experienced at Fort Sill.

2. The Simulation Facility

a. Mechanical and Structural Features

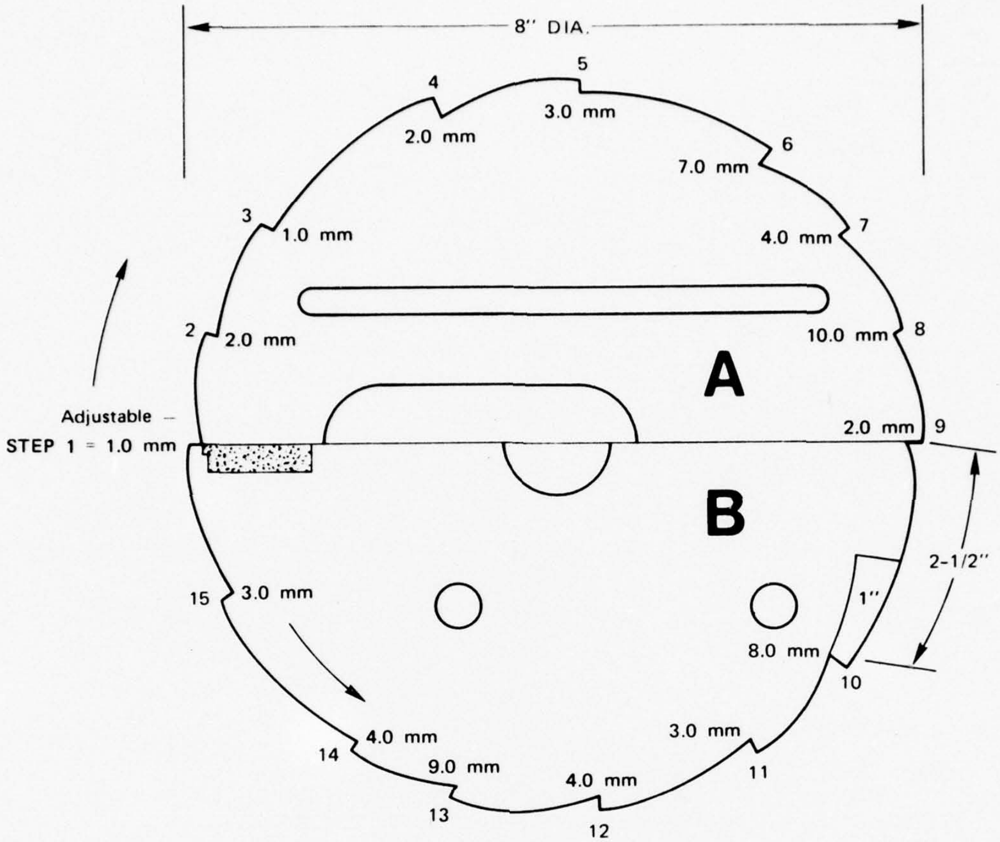
While doing earlier work for the National Aeronautics and Space Administration, a sonic boom simulator was built at SRI. This facility contains three separate rooms in which the vibrational and acoustic effects of sonic booms can be simulated. The simulation is intended to create, within these rooms, the same sounds and movements that would be present in a room of a typical frame house if that house were exposed to a sonic boom created by a supersonic aircraft. There is no provision for simulating the outdoor effects of sonic booms.

For this project, we have modified one sonic boom simulator so that complex waves such as long explosion sequences can be produced. The simulation is accomplished by driving a plunger sharply back and forth in a pneumatic plenum, one side of which is a room wall. The effect of the plunger motion is to load impulsively the wall of the room thus causing it to deflect or vibrate and causing acoustic waves to be generated in the room. The wall motion, the other motions induced in the remaining parts of the room structure, and the acoustic waves generated thereby are quite similar to the motions and waves caused in actual structures affected by sonic booms or explosions.

b. Cams

The vibrational and acoustic effects experienced by persons in the simulator are controlled mainly by the specific motion pattern of the plunger. This motion pattern, a rather complicated sequence of back and forth movements, is controlled by a cam upon which a cam follower rides. The cam follower, in turn, drives the plunger and produces an effect that is similar to an actual explosion sequence. Five of these cams are described by the sketches in Figures 1A through 5A. The sixth cam has an adjustable, single, sharp step with a current offset of 10 mm. The cams in Figures 1A, 2A, and 5A are designed to produce an indoor simulation of long explosion sequences, or group firings, such as those observed when many artillery pieces are fired almost simultaneously. These cams are made to rotate slowly for one revolution; although the time required can be widely varied, it is best set at about 4 to 10 s. Each step causes the plunger to move abruptly as the cam follower drops. The intensity of the vibrational and acoustic effect increases with the size of the step offset.

The cams in Figures 3A and 4A are designed to produce an effect similar to a single 8-in. howitzer shell impact explosion. These cams rotate not only faster than the group firing cams, but also for a

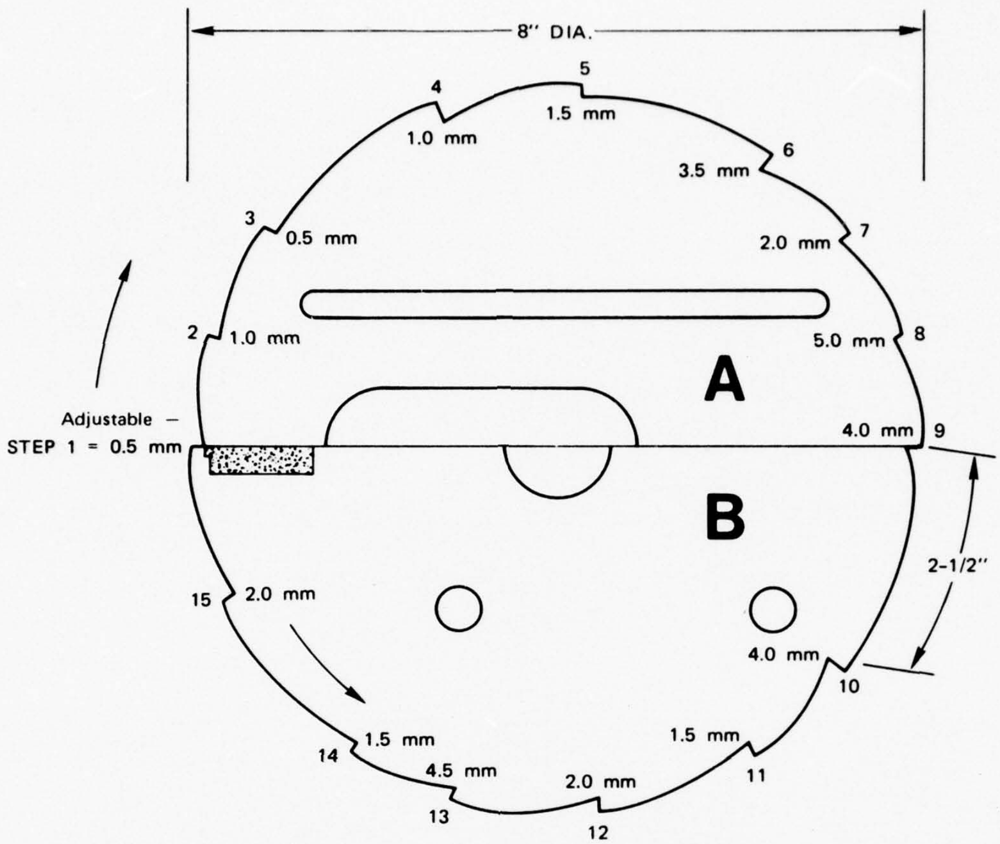


DISTANCE BETWEEN STEPS
1-1/4" from 1 to 2
1-1/2" from 2 to 3
3-3/4" from 3 to 4
1-1/4" from 4 to 5
1-1/4" from 5 to 6
1-1/4" from 6 to 7
1-1/4" from 7 to 8
1-1/4" from 8 to 9
2-1/2" from 9 to 10
1-1/4" from 10 to 11
1-1/2" from 11 to 12
1-1/4" from 12 to 13
1-1/4" from 13 to 14
2-1/2" from 14 to 15
2" Remaining Distance from 15 to 1

STEP NO.	OFFSET
1	1.0 mm
2	2.0 mm
3	1.0 mm
4	2.0 mm
5	3.0 mm
6	7.0 mm
7	4.0 mm
8	10.0 mm
9	2.0 mm
10	8.0 mm
11	3.0 mm
12	4.0 mm
13	9.0 mm
14	4.0 mm
15	3.0 mm
CAM NO. 1	LARGE

SA-3160-1

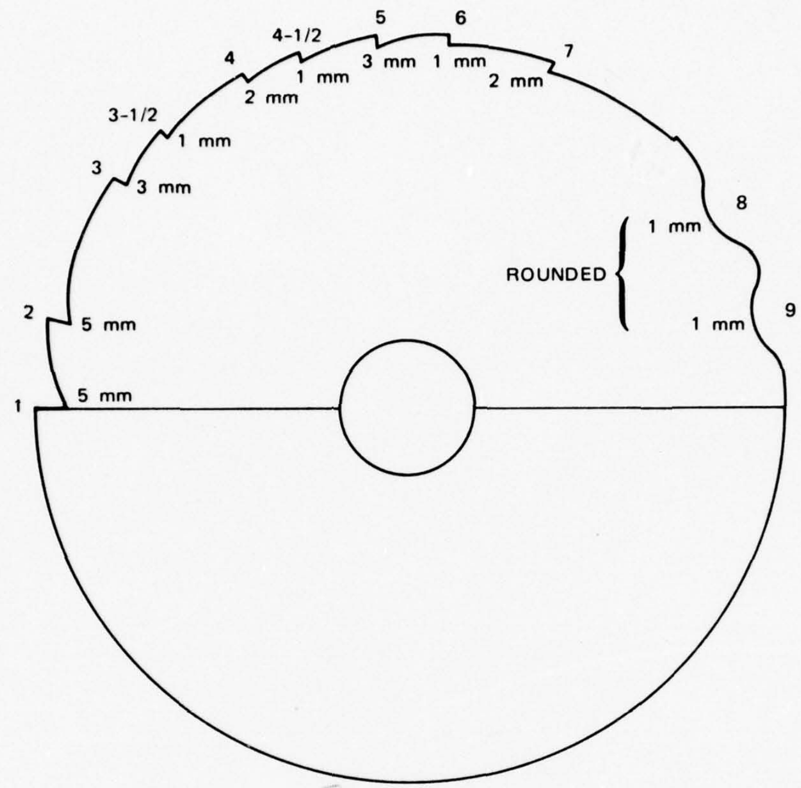
FIGURE 1A HIGH INTENSITY CAM SIMULATING ARTILLERY GROUP FIRING



DISTANCE BETWEEN STEPS	STEP NO.	OFFSET
1-1/4" Cam Half Cut from 1 to 2	1	0.5 mm
1-1/2" from 2 to 3	2	1.0 mm
3-3/4" from 3 to 4	3	0.5 mm
1-1/4" from 4 to 5	4	1.0 mm
1-1/4" from 5 to 6	5	1.5 mm
1-1/4" from 6 to 7	6	3.5 mm
1-1/4" from 7 to 8	7	2.0 mm
1-1/4" Cam Half Cut from 8 to 9	8	5.0 mm
2-1/2" from 9 to 10	9	4.0 mm
1-1/4" from 10 to 11	10	4.0 mm
1-1/2" from 11 to 12	11	1.5 mm
1-1/4" from 12 to 13	12	2.0 mm
1-1/4" from 13 to 14	13	4.5 mm
2-1/2" from 14 to 15	14	1.5 mm
2" Remaining Distance from 15 to 1	15	2.0 mm
	CAM NO. 2	MEDIUM

SA-3160-2

FIGURE 2A MEDIUM INTENSITY CAM SIMULATING ARTILLERY GROUP FIRING



DISTANCE BETWEEN STEPS

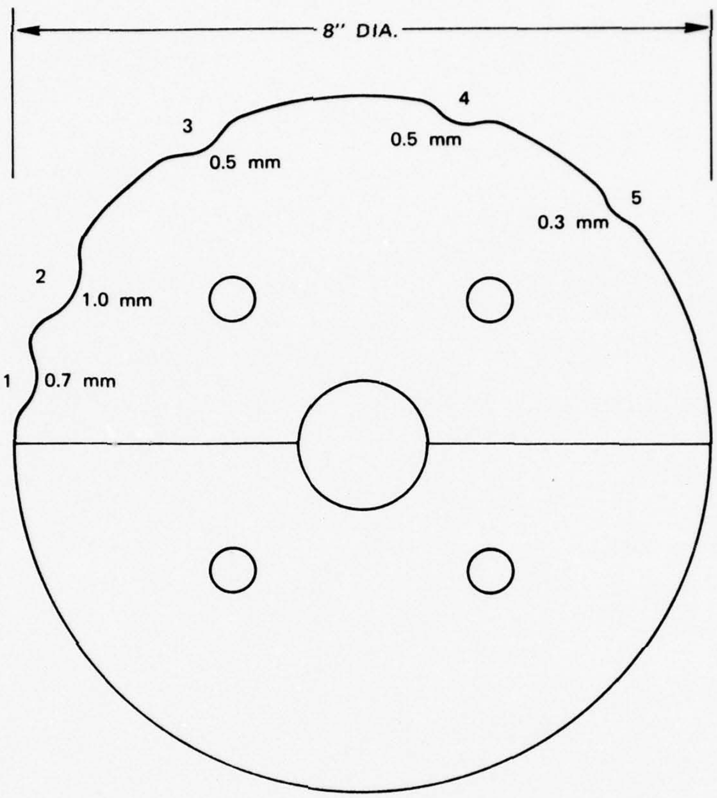
1" from 1 to 2
1-1/2" from 2 to 3
3/4" from 3 to 3-1/2
3/4" from 3-1/2 to 4
3/4" from 4 to 4-1/2
3/4" from 4-1/2 to 5
3/4" from 5 to 6
1-1/4" from 6 to 7
1-1/2" from 7 to 8
1" from 8 to 9

STEP NO.	OFFSET	
1	5 mm	
2	5 mm	
3	3 mm	
4	2 mm	
5	3 mm	
6	1 mm	
7	2 mm	
8	1 mm	Rounded
9	1 mm	Rounded

CAM NO. 3

SA-3160-3

FIGURE 3A MEDIUM INTENSITY SINGLE IMPULSE CAM SIMULATING 8-INCH HOWITZER IMPACT



DISTANCE BETWEEN STEPS

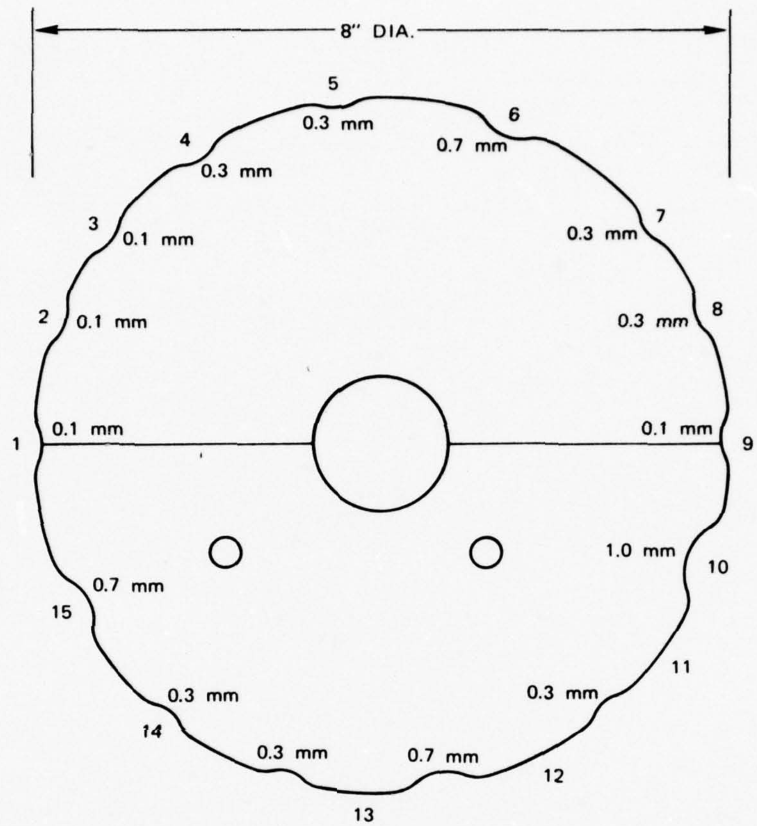
1/2" from 1 to 2
3/4" from 2 to 3
2-1/2" from 3 to 4
2" from 4 to 5

STEP NO.	OFFSET
1	0.7 mm
2	1.0 mm
3	0.5 mm
4	0.5 mm
5	0.3 mm

CAM NO. 4

SA-3160-4

FIGURE 4A LOW INTENSITY SINGLE IMPULSE CAM SIMULATION 8-INCH HOWITZER IMPACT WITH RUMBLE



DISTANCE BETWEEN STEPS

1-1/4"	from 1 to 2
1-1/2"	from 2 to 3
3-3/4"	from 3 to 4
1-1/4"	from 4 to 5
1-1/4"	from 5 to 6
1-1/4"	from 6 to 7
1-1/4"	from 7 to 8
1-1/4"	from 8 to 9
2-1/2"	from 9 to 10
1-1/4"	from 10 to 11
1-1/2"	from 11 to 12
1-1/4"	from 12 to 13
1-1/4"	from 13 to 14
2-1/2"	from 14 to 15

STEP NO.	OFFSET
1	0.1 mm
2	0.1 mm
3	0.1 mm
4	0.3 mm
5	0.3 mm
6	0.7 mm
7	0.3 mm
8	0.3 mm
9	0.1 mm
10	1.0 mm
11	0.3 mm
12	0.7 mm
13	0.3 mm
14	0.3 mm
15	0.7 mm

CAM NO. 5

SA-3160-5

FIGURE 5A LOW INTENSITY CAM SIMULATING GROUP FIRING WITH RUMBLE

single revolution. The reverberation, or rumble, accompanying the single explosion event is reproduced by a series of steps with diminishing offsets and, in some cases, by steps with rounded contours that cause softer cam follower drops.

c. Measurements

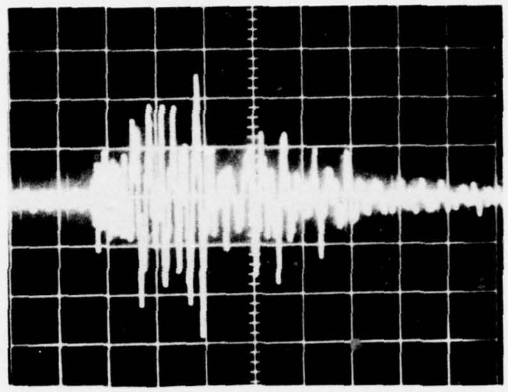
The effect of the cam design and plunger impact on the simulator wall plenum is measured by an accelerometer transducer and a condenser microphone. The accelerometer measurements are obtained by placing the transducer in the approximate center of the room wall next to the plenum. The microphone position is approximately at ear level for a seated person and on the center line of the room with respect to the plenum wall. Oscillographic traces are used to capture the vibration and acoustic data and for comparison with actual data recorded at Fort Sill.

In Figure 6A, four oscillographic traces of accelerometer data show real and simulated events, a single impact of an 8-in. howitzer projectile, and a multiple-impact sequence produced by group firing. Measured peak accelerations are listed in "G" units. The simulation seems quite good in these two cases, at least insofar as photographic comparison can be used as a measure of quality.

Oscillographic traces also are used to examine detailed features of the plenum wall response as shown in Figure 7A. In this case, a medium-intensity simulation of a group firing produces a 4-s vibrational pattern shown in the top trace. A small section of the midpart of this event can be extracted and expanded, however, as shown in the lower trace. The lower trace expansion permits one to see more clearly the wall movements and, to a first approximation, allows for the estimation of the frequencies of wall motion. In this case, the vibrational wall has either forced or natural frequencies up to about 100 Hz.

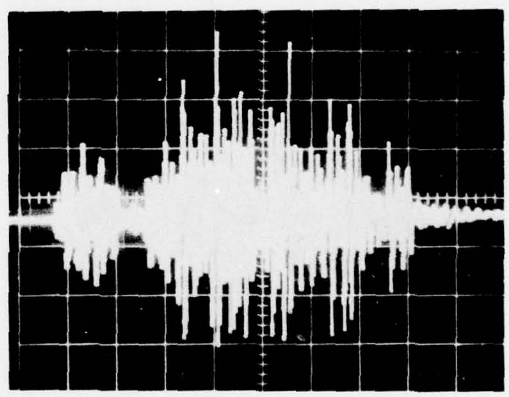
All of the cams built have been used to drive the simulator under controlled measurement conditions. The results of these measurements, peak accelerations in G units and peak sound pressure levels, are listed in Table A-1. These values are generally higher than those measured at Fort Sill because of the relatively poor acoustic propagation conditions existing at the time field data were obtained. Maximum values for the real data were in the neighborhood of 0.2 G and 110 dB SPL.

(a) (TOP TRACE) ENDEVCO ACCELEROMETER;
FORT SILL
8" HOWITZER IMPACT
HORIZONTAL 0.1 s/cm
+G = 0.02
0.6-s DURATION
(BOTTOM TRACE) UNCALIBRATED
MICROPHONE SIGNAL



(b) ENDEVCO ACCELEROMETER; SIMULATED
8" HOWITZER IMPACT
HORIZONTAL 0.1 s/cm
+G = 0.1 PEAK
0.6-s DURATION

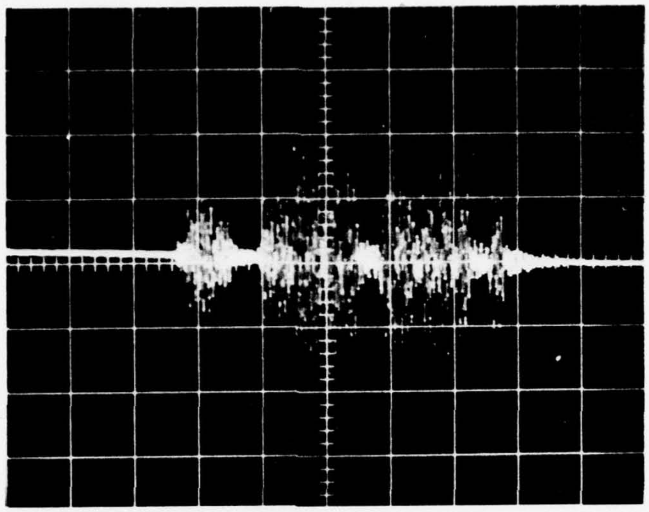
(c) FORT SILL GROUP FIRING IMPACT
(76 PIECES)
HORIZONTAL 1 s/cm
+G = 0.2
10-s DURATION



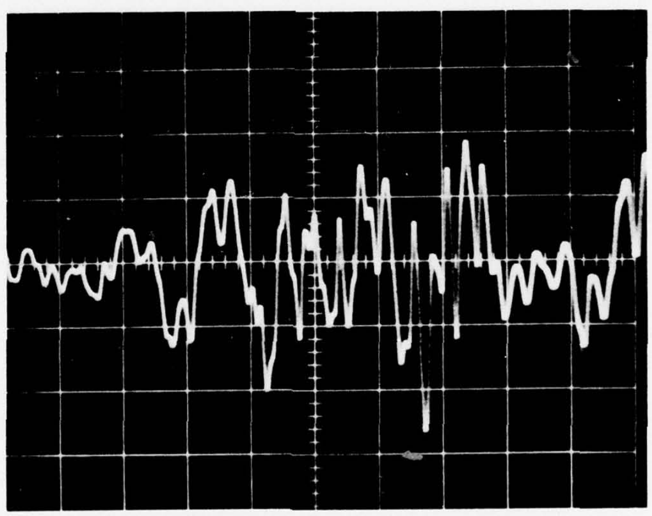
(d) SIMULATED GROUP FIRING
HORIZONTAL 0.5 s/cm
+G = 0.6 PEAK
4-s DURATION

SA-3160-7

FIGURE 6A COMPARISON OF REAL AND SIMULATED ARTILLERY IMPACTS



(a) MEDIUM INTENSITY SIMULATION OF ARTILLERY GROUP FIRING
HORIZONTAL 0.5 s/cm
+G = 0.4
4-s DURATION



(b) MIDSECTION OF ABOVE TRACE
HORIZONTAL 20 ms/DIVISION

SA-3160-6

FIGURE 7A MEDIUM INTENSITY SIMULATION OF GROUP FIRING WITH EXPANDED TRACE

Table A-1

PHYSICAL MEASUREMENTS OF SIMULATED ARTILLERY IMPACTS

Cam Type	Peak Force (G units)	Peak SPL (dB)
LIS	0.1	90
LIM	0.2	96
MIS	0.6	106
MIM	0.6	107
HIM	0.7	109.5
HISOS	0.7	112.5

3. Quality of the Simulation

The explosion sequences simulated during this work are to be used for studying the psychological effects of such sounds on people in communities near Army posts. Thus, the primary standard to be met by the simulation is that the sounds produced by the laboratory simulator be authentic in a perceptual sense when compared with actual sounds heard indoors. We consider secondary standards to be:

- Time duration comparisons.
- Amplitude vs. time comparisons of accelerometer and microphone signals.
- Frequency spectrum comparisons.

The comparison of simulated sequences with real sequences, when done perceptually, consists of listening to these sounds under the appropriate situations and making a judgment of similarity. In this case, the comparisons were made several months after the actual sounds were heard. Clearly, this method of comparison, though having the greatest face validity, is quite subjective and susceptible of error. Nevertheless, the subjective or perceptual comparison of sounds has been found in the past experience of laboratory and field work to be

more reliable than the usual method of comparison using signal analysis and physically measurable signals. Thus, the perceptual measure is considered the primary standard and the physical measures are considered to be useful secondary standards.

On 14 June 1974, the Contract Monitor from CERL, Dr. Paul Schomer, visited our facility and heard our simulations. Dr. Schomer and the laboratory personnel of SRI perceptually evaluated, using the best judgment possible, the sounds then available. This evaluative session, which also included examination of certain physical data, resulted in the modification of several cams, particularly those used to simulate low-intensity, single explosions and explosion sequences. The modifications produced an improved percept of "rumble" or reverberation that is correlated (though imperfectly) with a reduction of high-frequency energy vis-a-vis low-frequency energy. The medium- and high-intensity simulations were judged to be adequate, but perhaps too rich in high-frequency components; these components were reduced (but not to a "rumble") by softening certain sharp steps in the representative cams. Consequently, by July 1, or so, effective changes had been made in the set of cams used by the simulators so that, in the opinion of SRI personnel, a good simulation of the field observations of November, 1973 had been obtained.

The secondary standards of quality have also been applied, but have not yet been completely evaluated. In general, however, we feel that duration and gross amplitude/time comparisons between real and simulated events are exceptionally good. Detailed waveform analysis reveals a weakness; the room walls in the building at Fort Sill have lower natural frequencies and fewer natural modes than does our simulator wall. We feel that this is not a significant weakness because our simulator wall was designed to be typical of frame construction used in modern residential housing. On the other hand, the Fort Sill building, by virtue of extensive remodeling (that included the addition of 3/4 in. plywood paneling throughout the interior) and an age of possibly 50 years, is no doubt far from typical.

Frequency domain analysis is usually an effective method for comparing signals. In this case, the application of this method was hindered because our original tape-recorded data were contaiminated by wind noise. This situation was unavoidable at the time of the recording because acoustic propagation conditions during the firepower demonstration were such that the explosion effects were sometimes only marginally greater than the sound and vibration caused in the test building by strong and gusty winds. Nonetheless, our current data do show that to the extent such comparisons are valid our simulations and the real data compare well on gross features. Fine feature comparisons

(such as of the distribution and amplitude of natural motion modes) are almost impossible to make in the frequency data, but are presumably irrelevant because the amplitude/time data do permit a somewhat reasonable comparison and show the data to be mostly dissimilar.

Appendix B

A PILOT EXPERIMENT TO MEASURE THE PSYCHOLOGICAL ANNOYANCE OF SIMULATED ARTILLERY EXPLOSIONS AND RECORDED AIRCRAFT NOISE

On 10 and 11 July 1974, a pilot experiment was conducted in our simulation facility. Each of thirteen adult subjects participated in one of three 1-hour sessions: two sessions on 10 July and one session on 11 July. Because three subjects failed to follow exactly the instructions of the experimenters, their data had to be discarded. Ten subjects, seven females and three males, produced valid data.

Each experimental session began with the reading of the general instruction sheet reproduced in Figure 1B at the end of this appendix. The instructions were discussed and the experimenter answered any questions. Each subject then was given a set of three special forms to be used to record their ME responses. The first sheet of this set is reproduced in Figure 2B. The remaining two sheets contained number response lines 6 through 38; these were identical to lines 1 through 5 on the first sheet of the set. Subjects filled out the heading on Sheet 1 as indicated and reread the instructions to be followed in responding to the noise stimuli to be presented later.

A sequence of noises, listed and described in Table B-1, was presented to each subject in the group. The sequence number was announced before the presentation of each noise; whenever the reference noise occurred, it was identified as such in the announcement.

Table B-2 contains the raw data collected from the ten subjects who responded correctly to the experimental procedure instructions. For each noise, or for each presentation of a noise, means and standard deviations of each response set are listed.

For the pilot experiment, five fixed subject positions were established. All positions were occupied in the first two sessions, and three were occupied in the third session. The conditions in the room were such that practically identical acoustical stimuli were present at all subject positions when the explosion simulator was activated and there was a 1.5 dB(A) range (of maximum values) across positions when the aircraft noises were presented over the loudspeaker.

The simulated explosions and explosion sequences are described in Appendix C. The aircraft noises were obtained from recordings made earlier at San Francisco International Airport. The recordings, made

INSTRUCTIONS

The purpose of the test to be conducted today is to determine the relative acceptability and tolerability of noises from various weapons fired on U.S. Army training bases when heard by people in or near their homes at various distances from the training base. The information from this and related studies is useful in measuring the characteristics of different types of noises and in providing means to reduce or control these noises so that they will be more acceptable to people exposed to them.

We want you to judge the noises you will hear as though you were listening to them in your home when engaged in typical, everyday, activities such as reading, conversing with friends, or family, etc. It is important that you judge the effect of each noise in its entirety from beginning to end as an overall noise occurrence.

You may like or dislike any of the noises you hear, but we want you to judge the noises relative to a reference noise. During each test session, you will be presented first with a flyover noise from an aircraft to which you will listen and assign the number 10 on your answer sheet. This is the reference noise. Please score each succeeding noise that you hear relative to the reference noise that was presented. If, for example, a noise sounds to you twice as bothersome, noisy, unwanted, or disturbing as the reference noise would be if you heard it in your home while engaged in typical activities, score the noise as having a value of 20; since the reference noise had a score of 10. Mark the answer sheet accordingly. However, if the noise appears one-half or one-quarter as noisy or unwanted as a reference noise, mark your answer sheet accordingly;

- if it is one-half as noisy, its score is 5.
- if it is one-fourth as noisy, its score is 2.5.

The answer sheet is to be used for assigning a numerical score to each of the noises you will hear. Remember, it is your subjective impression that is important. There are no right or wrong answers nor do we expect people to agree with each other. We are interested in how you feel about these sounds and how people differ in their judgments of these noises.

Figure 1B GENERAL INSTRUCTIONS TO SUBJECTS

ANSWER SHEET

NAME______________________________________DATE____________________

AGE______________SEX_______________SESSION_______________

First, we will present a sound whose noisiness score is 10. Using that sound as a Reference, with the score of 10, judge each succeeding sound in relation to that Reference sound and number; for example, if a succeeding sound seems to be twice as noisy or objectionable to you if heard in or near your home during normal activities, mark the line at "20" (or 2 times, 2X), or if a succeeding sound seems half as objectionable, mark the line at "5" (or 1/2X), or if a succeeding sound seems equal to the Reference sound mark 10 or 1X, and so forth. If a sound or noise seems to be more than twice but not quite four times as noisy or objectionable as the Reference sound, mark the line between 20 (2X) and 40 (40X) at the place you think is the most appropriate.

Remember, judge each noise with respect to the Reference sound, giving the Reference sound a score of 10. Rate each noise as you would if you heard it in or near your home when engaged in average activities. You may mark the line beyond the printed numbers if you feel the noise is greater, or less than, the extremes shown.

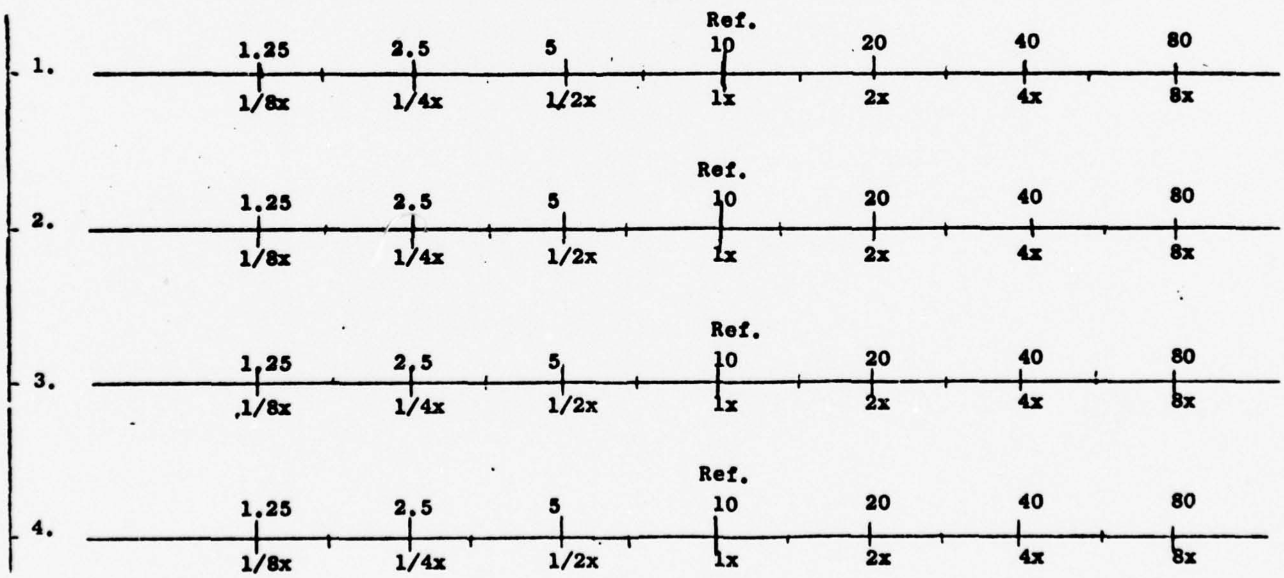


Figure 2B FACSIMILE DATA SHEET WITH FIRST 5 SUBJECT RESPONSE LINES

Table B-1

SEQUENCE OF NOISES PRESENTED TO SUBJECTS DURING THE PILOT EXPERIMENT

Sequence No.	Noise or Noise Source	dB(A)	Remarks
1	B 747 TO*	70	Reference noise; subject orientation
2	B 747 TO	70	Reference noise; subject orientation
3	B 747 TO	70	Reference noise; subject orientation
4	B 747 TO	70	Reference noise; subject orientation
5	LIS		Low-intensity, single-impact cam
6	B 747 TO	60	
7	B 747 TO	50	
8	DC 8 L†	80	
9	B 747 TO	70	Reference noise
10	LIM		Low-intensity, multiple-impact cam
11	DC 8 L	50	
12	DC 8 L	70	
13	B 747 TO	70	Reference noise
14	MIM		Medium-intensity, multiple-impact cam
15	B 747 TO	70	Reference noise
16	B 747 TO	70	Reference noise
17	MIS		Medium-intensity, single-impact cam
18	B 747 TO	70	Reference noise
19	B 747 TO	90	
20	B 747 TO	70	Reference noise
21	HIM		High-intensity, multiple-impact cam
22	B 747 TO	70	Reference noise
23	MIM		
24	B 747 TO	70	Reference noise
25	MIS		
26	B 747 TO	70	Reference noise
27	HISOS		High-intensity, single-offset cam
28	B 747 TO	80	
29	DC 8 L	90	
30	B 747 TO	70	Reference noise
31	HISOS		
32	B 747 TO	70	Reference noise
33	HIM		
34	B 747 TO	70	Reference noise
35	LIS		
36	B 747 TO	70	Reference noise
37	LIM		
38	DC 8 L	60	

*All B 747 recordings are of takeoffs (TO).
†All DC 8 recordings are of landings (L).

Table B-2

MAGNITUDE ESTIMATES, BY SUBJECT, OF PSYCHOLOGICAL ANNOYANCE CAUSED BY AIRCRAFT AND SIMULATED ARTILLERY NOISES

Noise or Noise Source	Subject										Mean	σ
	1	2	3	4	5	6	7	8	9	10		
B 747 TO, dB(A)												
90	60	30	40	60	80	50	30	20	20	40	43.0	19.5
80	20	15	20	40	60	15	20	20	20	20	25.0	15.1
70	10	10	10	10	10	10	10	10	10	10	10.0	0.0
60	10	6.6	6.6	6.6	1.25	10	10	5	2.5	1.25	6.0	3.4
50	2.5	3.3	5	5	1.25	6.6	5	2.5	1.25	1.25	3.4	1.9
DC 8 L, dB(A)												
90	60	30	40	80	100	40	30	40	40	80	54.0	24.6
80	60	20	20	30	40	20	40	20	20	20	29.0	13.7
70	15	15	6.6	20	20	10	15	10	5	20	13.7	5.6
60	5	5	6.6	6.6	5	5	6.6	5	1.25	1.25	5.3	1.6
50	1.7	2.5	3.3	5	5	2.5	6.6	5	2.5	1.25	3.5	1.8
LIS												
Trial 1	5	1	2.5	10	1	2.5	5	1.25	1.25	2.5	3.2	2.8
Trial 2	2.5	1.25	5	5	1.25	2.5	2.5	1.25	1.25	1.25	2.4	1.5
LIM												
Trial 1	40	1.7	20	10	10	30	10	5	1.25	2.5	13.0	13.1
Trial 2	15	2.5	15	15	5	10	10	2.5	5	1.25	8.1	5.6
MIS												
Trial 1	40	3.3	80	30	6.6	40	20	10	10	20	26.0	23.1
Trial 2	30	6.6	20	20	5	40	10	10	6.6	20	16.8	11.5
MIM												
Trial 1	40	3.3	80	20	15	40	10	10	1.25	5	22.5	24.5
Trial 2	60	5	30	20	15	30	10	10	5	20	20.5	16.6
HISOS												
Trial 1	6.6	2.5	20	6.6	1.25	5	5	5	6.6	1.25	6.0	5.3
Trial 2	5	2.5	10	15	1.7	5	6.6	5	6.6	1.25	5.9	4.1
HIM												
Trial 1	40	5	60	40	10	40	10	10	5	20	24.0	19.4
Trial 2	60	15	30	20	15	30	10	10	6.6	20	21.7	15.6

*Reference noise, assigned a magnitude of 10.

outdoors, were altered by a filter (called a "House Attenuation Filter" in Appendix C) so that the aircraft sounds received by our subjects in this pilot experiment were similar to the indoor sounds made by aircraft passing over a typical frame house.

Appendix C

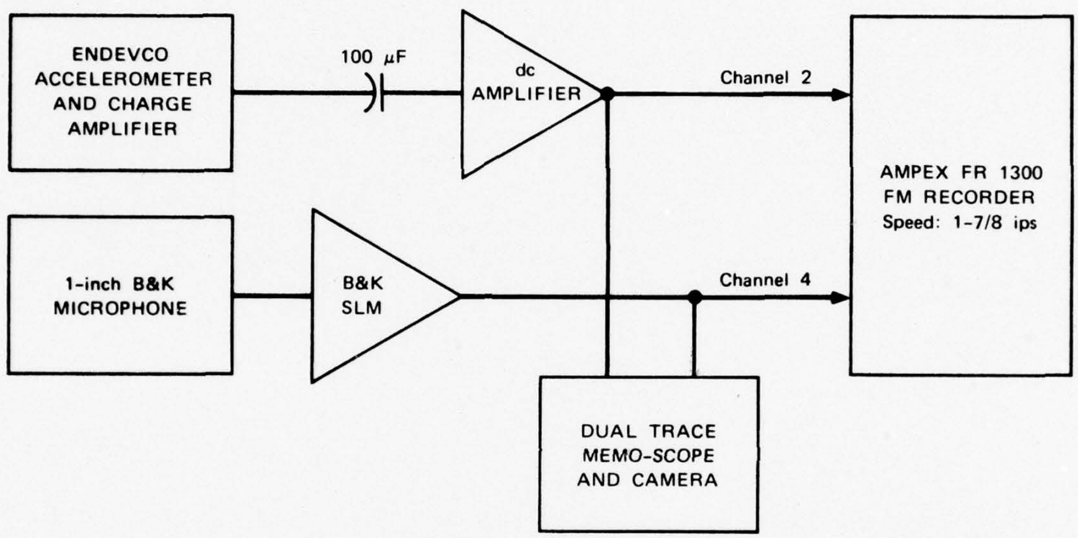
PHYSICAL ANALYSIS OF NOISE STIMULI USED IN THE PILOT EXPERIMENT

The noise stimuli used in the pilot experiment were of two distinct types; aircraft flyover noises and explosion-like noises produced by the mechanical/pneumatic actions of the simulator. The aircraft noises were of relatively long duration from 10-20 s, were slowly varying in level, and had dominant frequency spectral peaks of energy or power in the range 500-1000 Hz. On the other hand, the simulated explosions were of short duration (less than 1 s to at most 4 s); varied rapidly in level; and had frequency spectral peaks of energy at 100 Hz, or less.

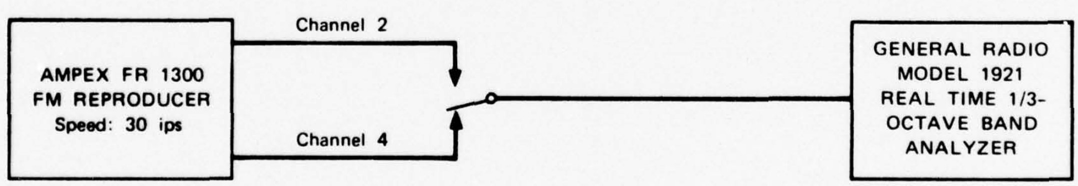
Because the two classes of stimuli varied significantly, two different methods of analysis were used. The aircraft noises were measured by standard sound-measuring methods; a sound level meter with the standard A-weighting and a slow meter setting was used for measurement and level control during the presentation of the stimulus.

The simulated explosions, however, were analyzed by first multiplying the frequency components of each noise (as recorded on an FM tape recording) by a factor of 16 and then decomposing the noise by 1/3-octave band filters. This process is generally equivalent to passing the noise through a 1/3-octave band parallel filter bank with center frequencies 1/16 the size of those of the standard or actual filter bank. This multiplication process yields an analysis of each noise that is descriptive of noise frequency components down to about 3 Hz when used with our available General Radio 1921 1/3-octave band analyzer. Estimates of energy components at such low frequencies may be unreliable and irrelevant, depending on the duration of the noise signal and the purposes for which the data are obtained. In our case, we used data from the bands spanning the range 10-500 Hz.

The block diagram of the frequency-multiplication analysis system appears in Figure 1C. Two channels of data were recorded: an accelerometer channel and a condenser microphone channel. The accelerometer data were most useful while we were adjusting the simulator system and modifying the cam component of that system. The microphone data were used to predict the psychological data and are of greater interest so far as this report is concerned.



(a) RECORDING/FREQUENCY MULTIPLYING SYSTEM



(b) REPRODUCING/FREQUENCY MULTIPLYING AND ANALYSIS SYSTEM

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FIGURE 1C FREQUENCY-MULTIPLICATION ANALYSIS SYSTEM BLOCK DIAGRAM

As the data were recorded, a scope-mounted camera was used to photograph the simulated explosion waveforms. These waveforms are shown in Figure 2C(a)-(g) along with the calibration signal waveform. The sound level meter (SLM) setting is given for each photograph so that absolute amplitude measures can be read from each picture. Horizontal sweep speeds are also given so that time durations can be read.

As shown in Figure 1C, the data recorded on the FM machine at 1-7/8 in. per s were reproduced on the same machine at 30 in. per s tape speed and thus yielded the X16 frequency multiplication. Each data channel, as it was reproduced, was analyzed by the General Radio 1921 real-time 1/3-octave band analyzer. The analyzer was adjusted for a 1-s integration time, a time much greater than the duration of any of the simulated explosions; when the original data were reproduced at a speed 16 times greater than that at which they were recorded, the maximum duration of the data signals was about 5/16 s. On the assumption of a very low signal background noise when the data signal was not present, the analyzer output under these conditions is a measure of the total energy in the signal in a given 1/3-octave band. The results of these analyses are plotted in Figures 3C through 8C. For comparison, Figures 9C and 10C are included to show results obtained by analyzing actual data recorded at Fort Sill, Oklahoma during field experiments in November, 1973.

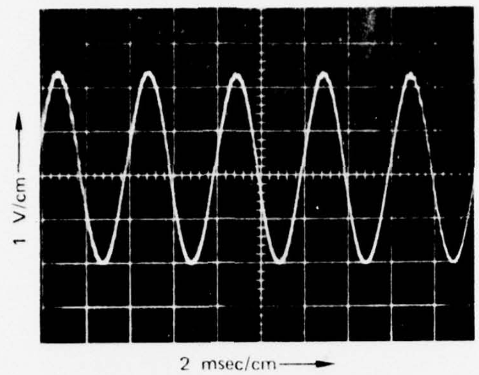
Standard analyses of the aircraft noises used are included in Table C-1. These aircraft noises, amplified or attenuated, were the stimuli used in the pilot experiment. The table shows measurements with

Table C-1

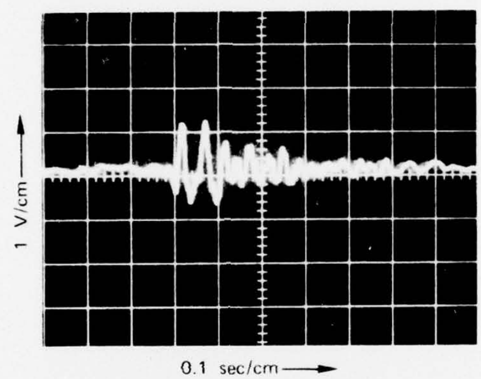
RELATIVE PHYSICAL MEASURES OF AIRCRAFT NOISES
REPRODUCED THROUGH A HOUSE ATTENUATION FILTER

Stimulus	dB (linear)	dB(C)	dB(A)	dB(D_2)
B 747 TO	115	115	107	112
DC 8 L	115	115	110	117

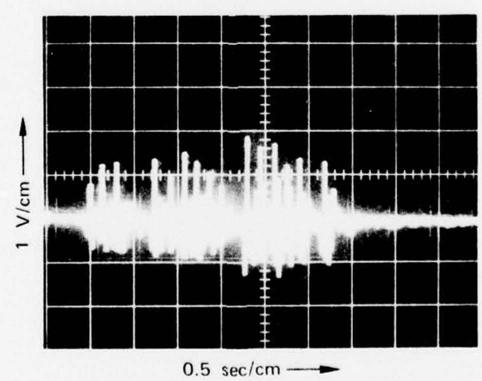
four frequency weightings: linear (flat 20-20,000 Hz), standard C-weight, standard A-weight, and the more recently devised D_2-weight. The numbers are the maximum values measured during a single, complete presentation of the specified noise.



(a) CALIBRATION SIGNAL FROM PISTONPHONE; SLM AT 120



(b) LOW INTENSITY SINGLE IMPULSE; SLM AT 90



(c) LOW INTENSITY MULTIPLE IMPULSE; SLM AT 90

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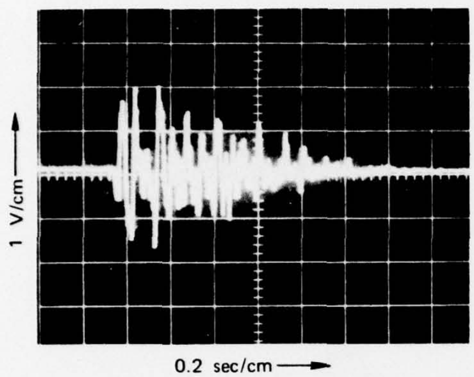
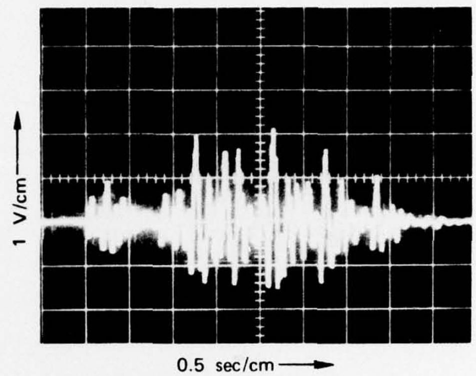
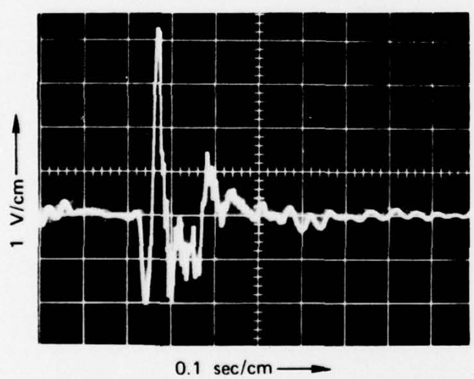
FIGURE 2C



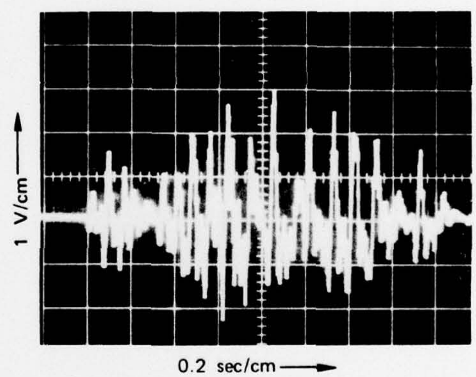
(d) MEDIUM INTENSITY SINGLE IMPULSE; SLM AT 100



(e) MEDIUM INTENSITY MULTIPLE IMPULSE; SLM AT 100



(f) HIGH INTENSITY SINGLE OFFSET CAM IMPULSE; SLM AT 100



(g) HIGH INTENSITY MULTIPLE IMPULSE; SLM AT 100

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FIGURE 2C (Concluded)

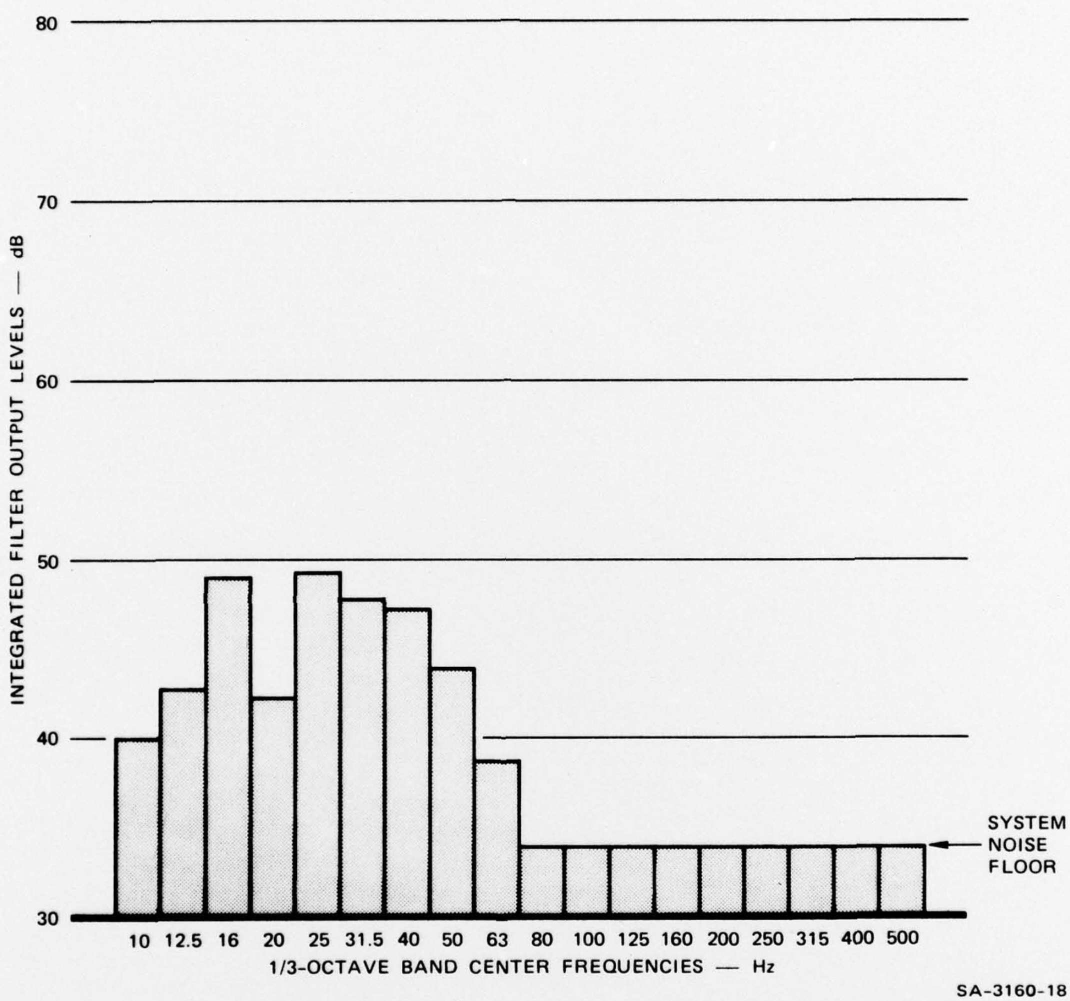

FIGURE 3C ENERGY SPECTRUM OF LOW INTENSITY, SINGLE IMPACT CAM (LIS)

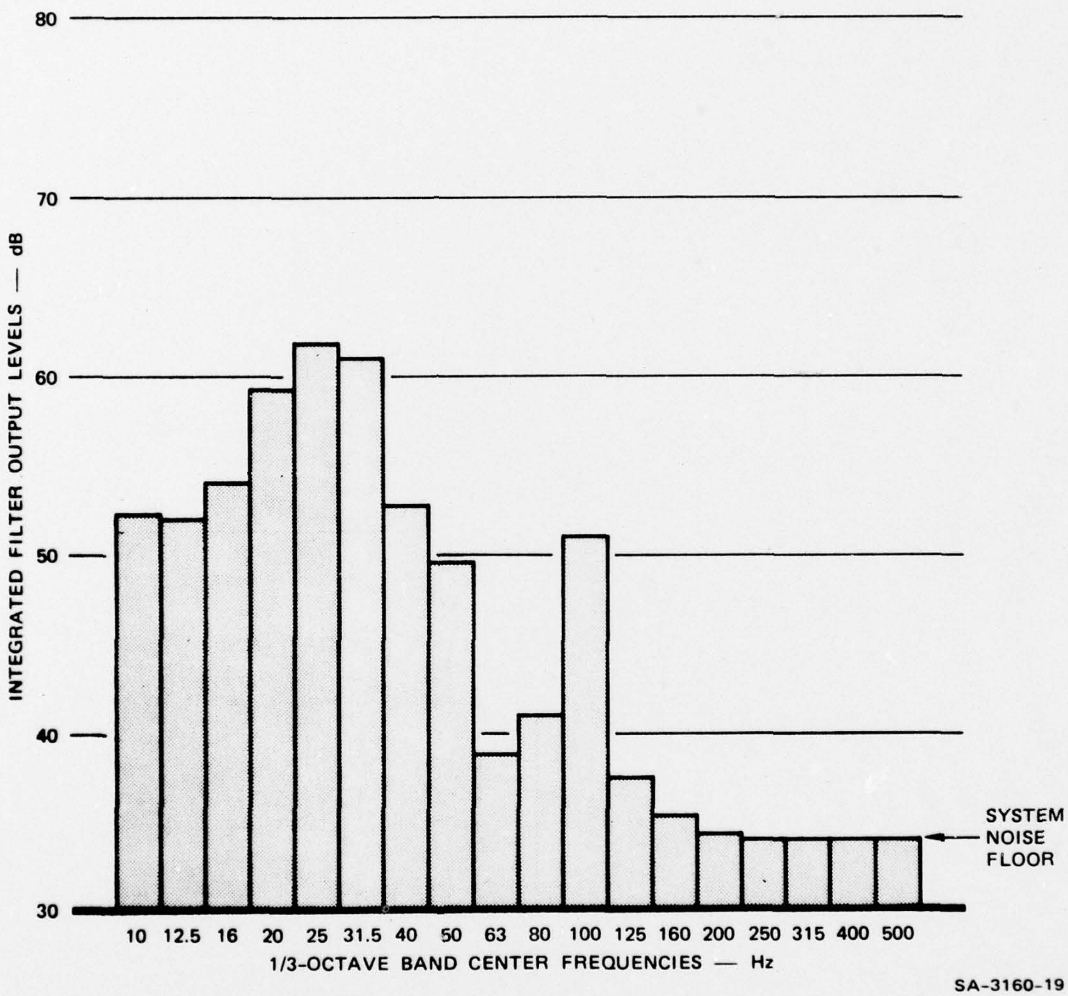

FIGURE 4C ENERGY SPECTRUM OF LOW INTENSITY, MULTIPLE IMPACT CAM (LIM)

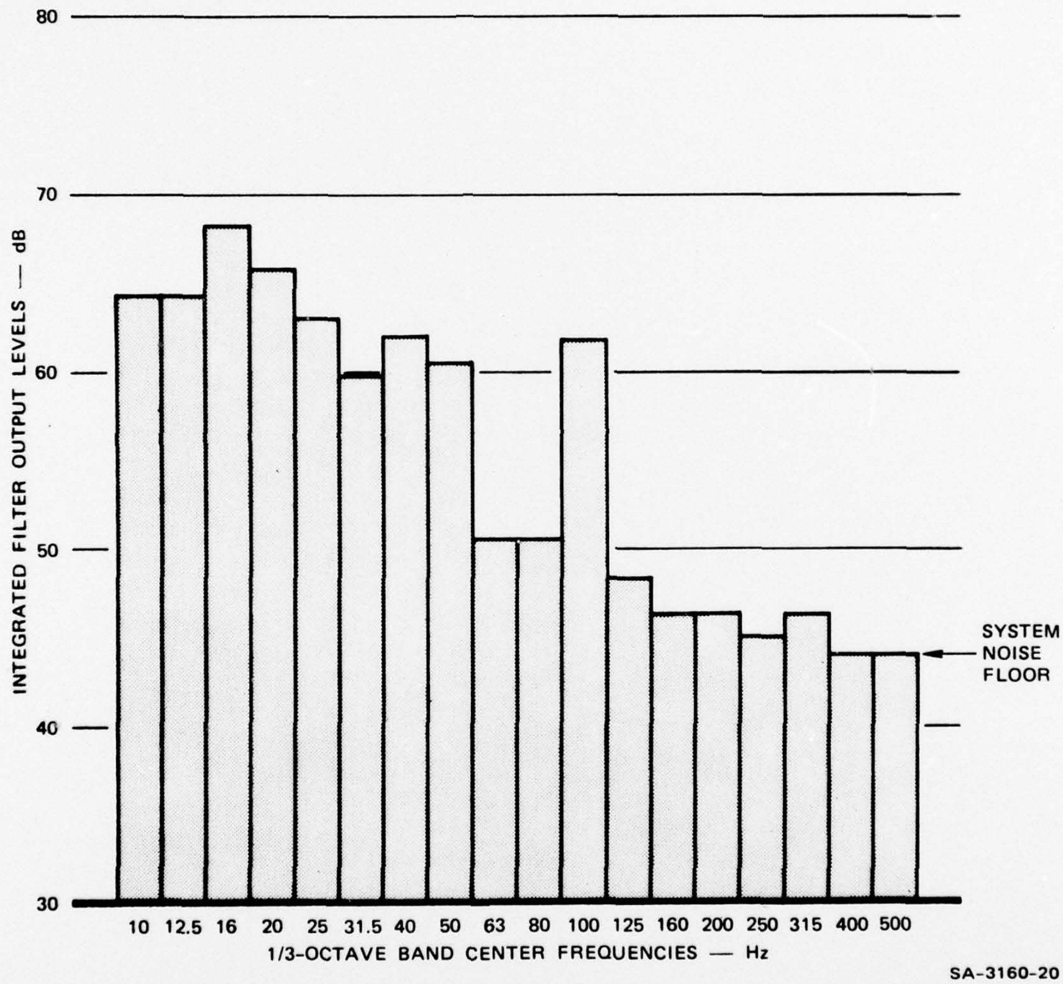

FIGURE 5C ENERGY SPECTRUM OF MEDIUM INTENSITY, SINGLE IMPACT CAM (MIS)

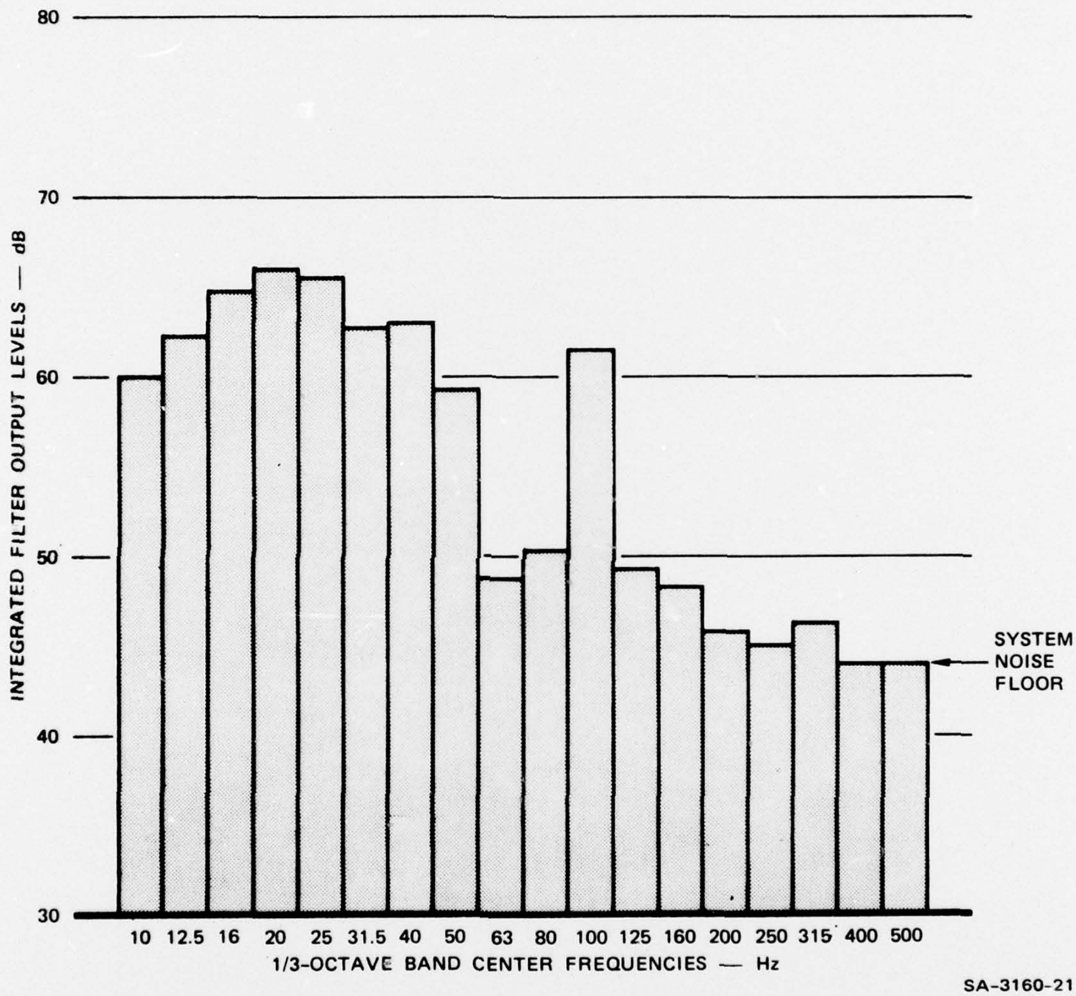

FIGURE 6C ENERGY SPECTRUM OF MEDIUM INTENSITY, MULTIPLE IMPACT CAM (MIM)

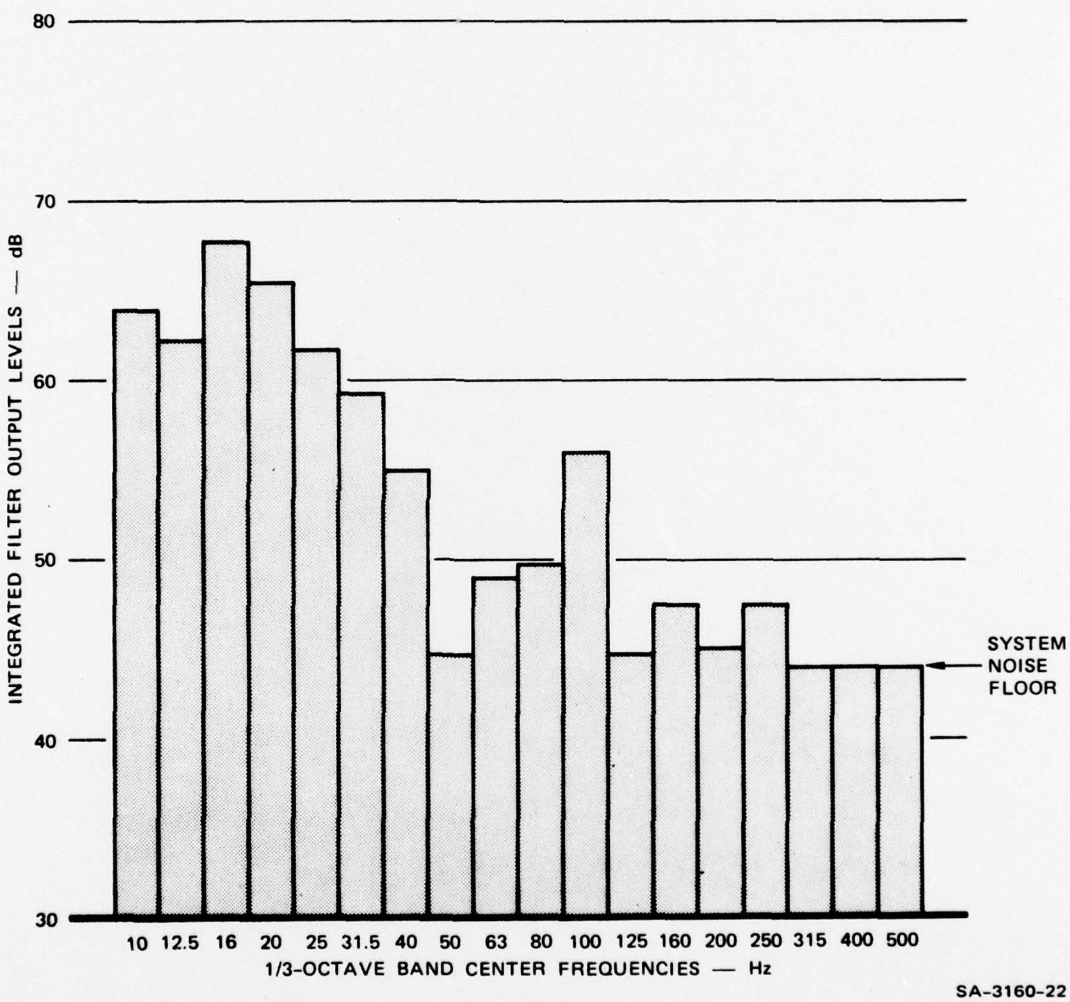

FIGURE 7C ENERGY SPECTRUM OF HIGH INTENSITY, SINGLE OFFSET CAM (HISOS)

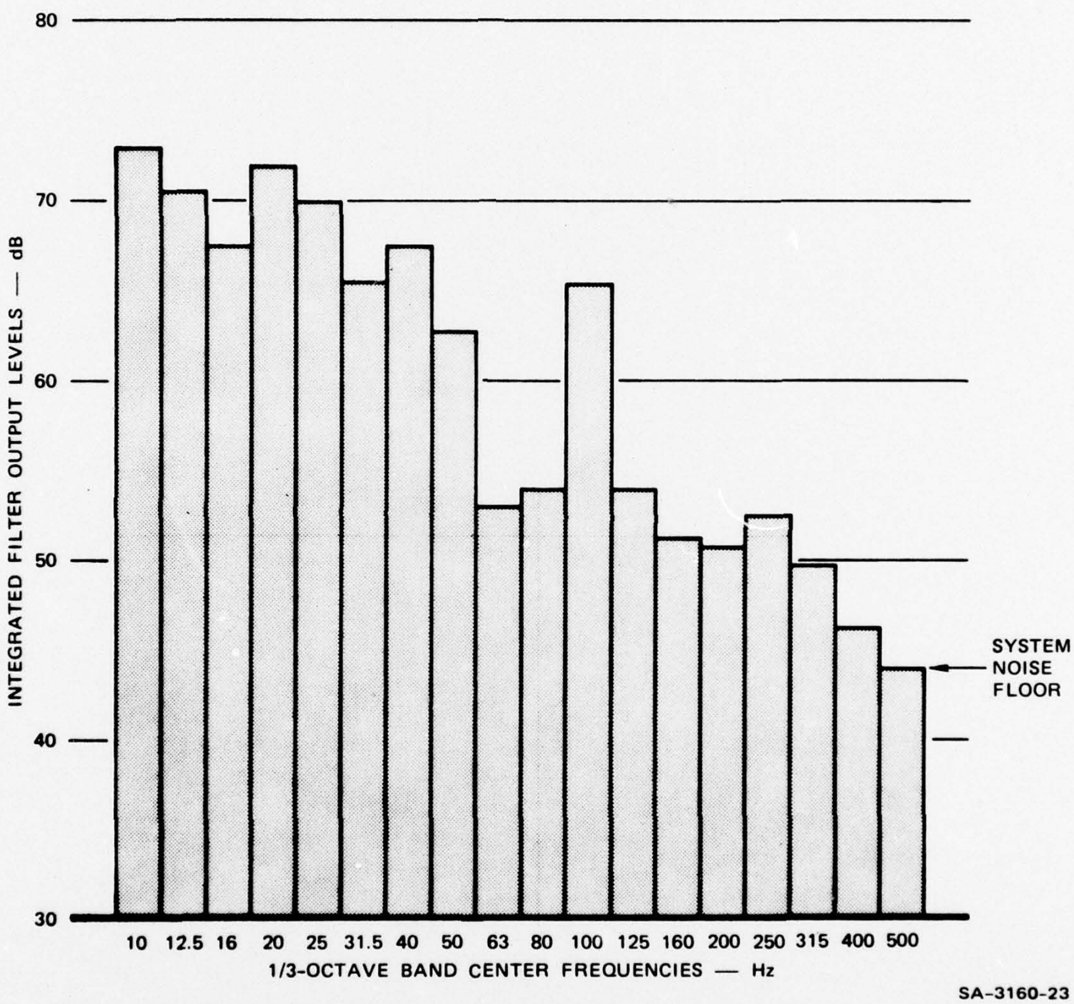

FIGURE 8C ENERGY SPECTRUM OF HIGH INTENSITY, MULTIPLE IMPACT CAM (HIM)

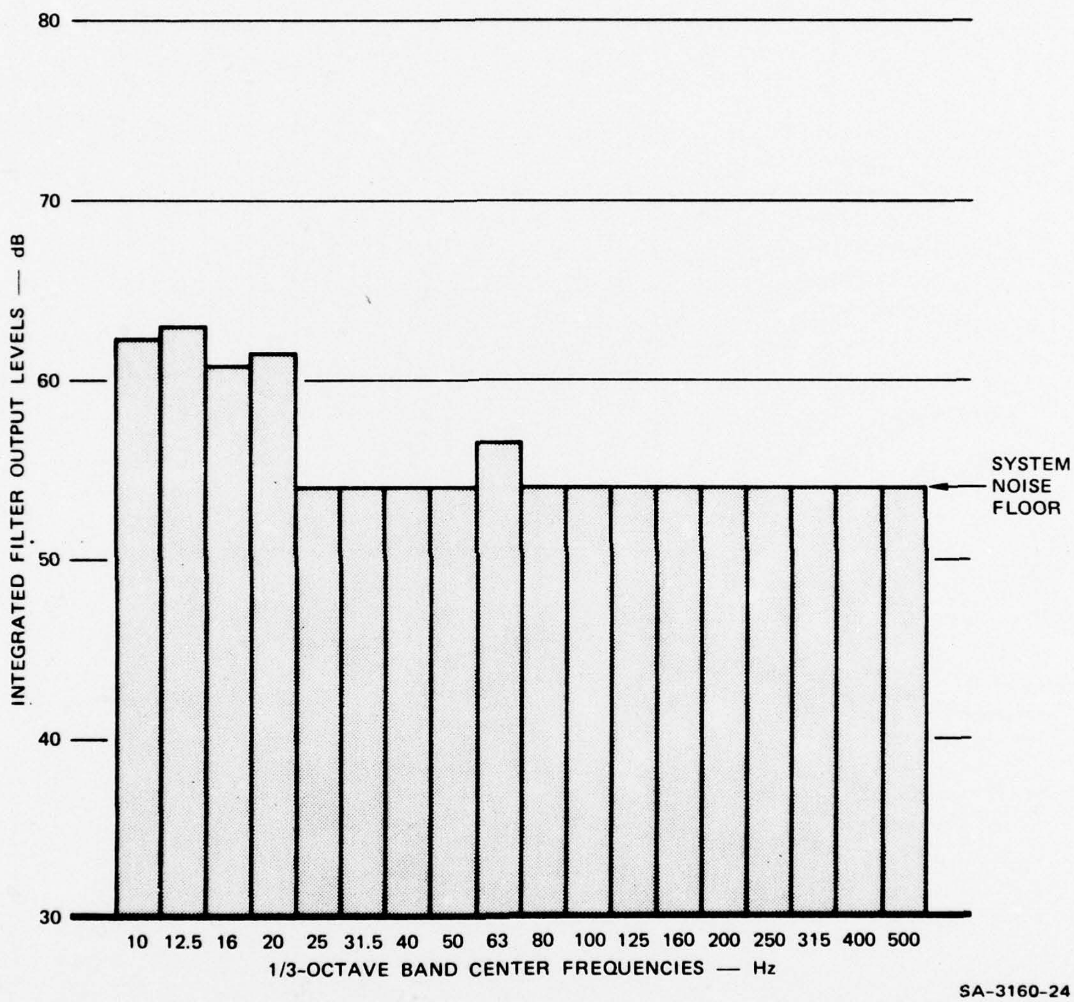

FIGURE 9C ENERGY SPECTRUM OF AN 8-INCH SELF-PROPELLED HOWITZER MUZZLE BLAST

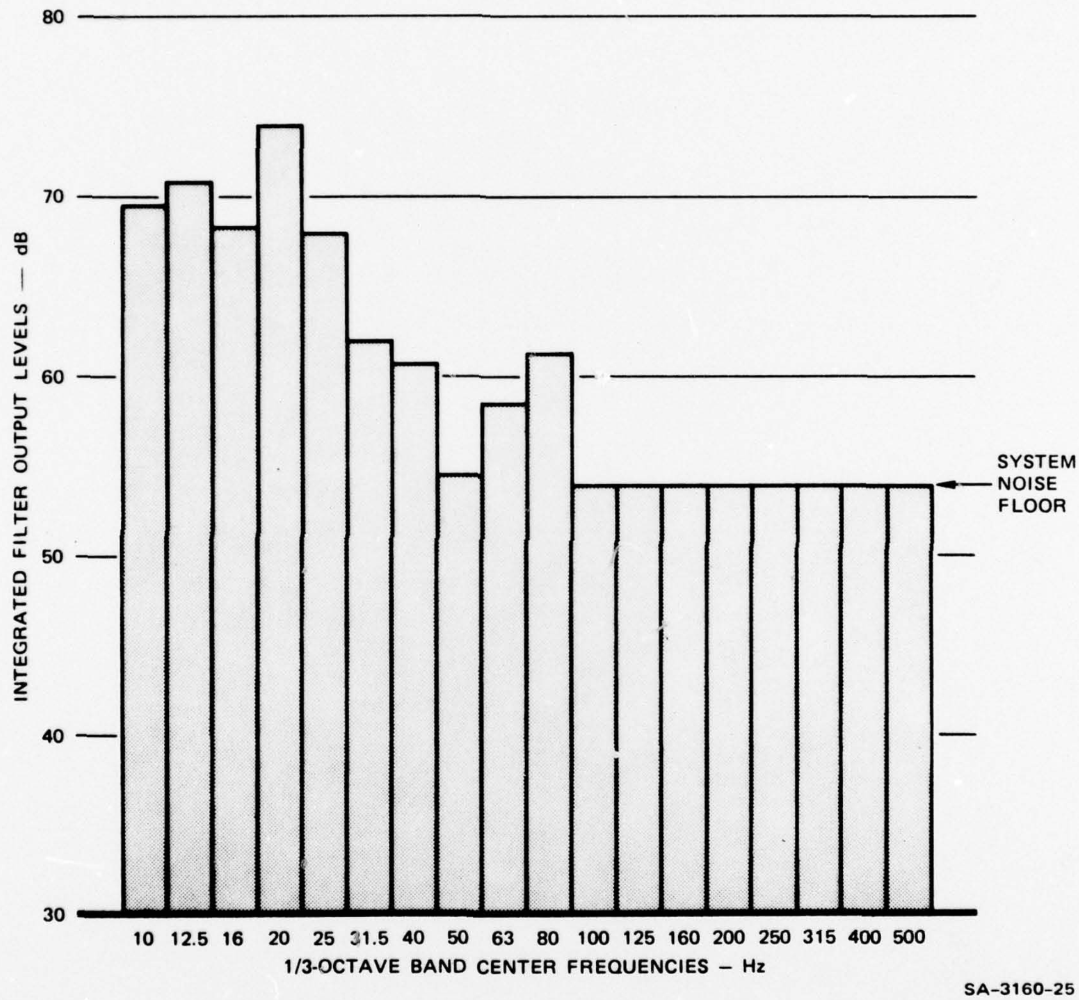

FIGURE 10C ENERGY SPECTRUM OF 76-PIECE GROUP FIRING

Figures 11C, 12C, and 13C are the frequency weighting curves used to produce the total energy measures Σ_edB(A), Σ_edB(D1), and Σ_edB(D2). These curves differ from the normal curves because they extend down to 10 Hz. This extrapolation was necessary so that the very low-frequency energy components present in the simulator noises could be accommodated.

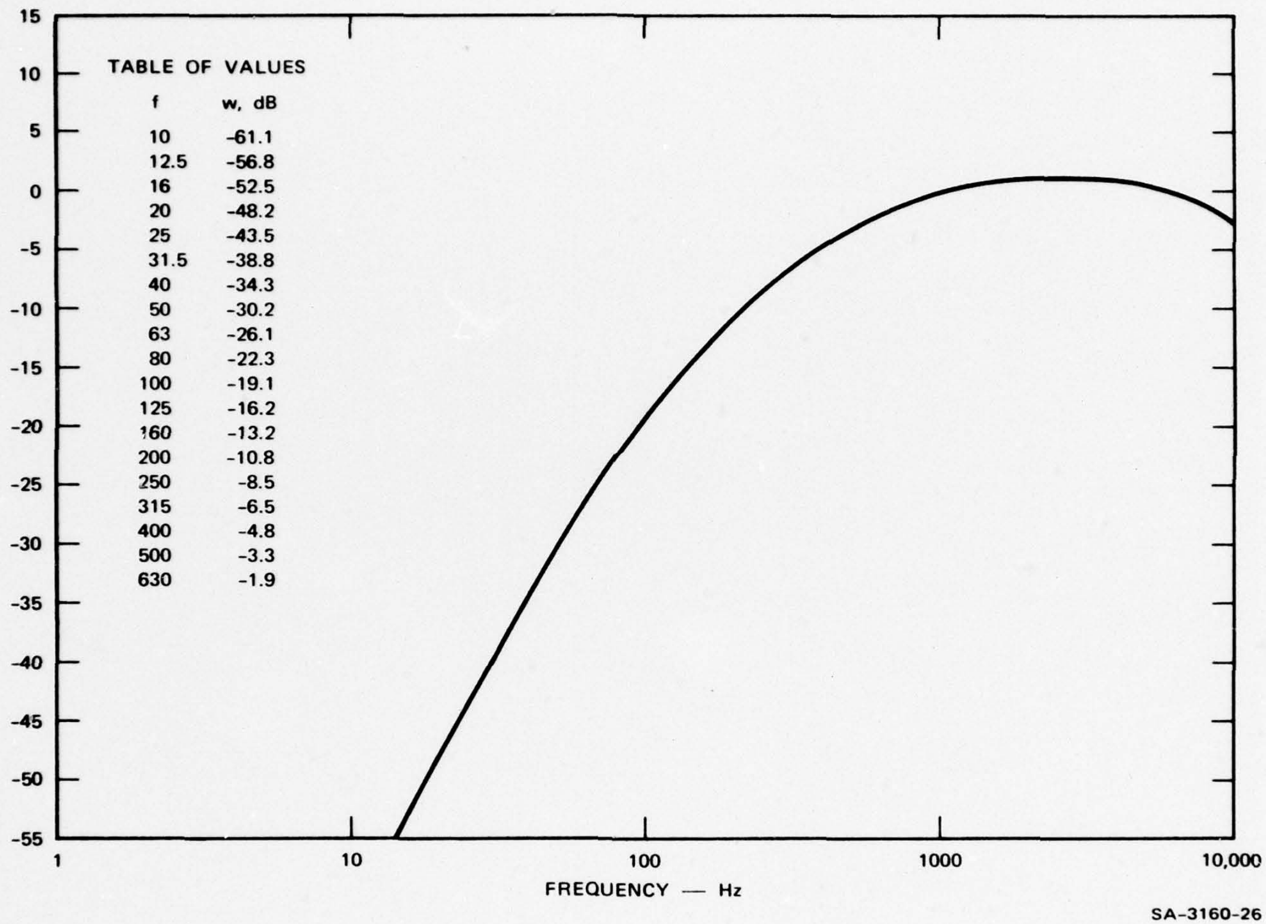

TABLE OF VALUES

f	w, dB
10	-61.1
12.5	-56.8
16	-52.5
20	-48.2
25	-43.5
31.5	-38.8
40	-34.3
50	-30.2
63	-26.1
80	-22.3
100	-19.1
125	-16.2
160	-13.2
200	-10.8
250	-8.5
315	-6.5
400	-4.8
500	-3.3
630	-1.9

FIGURE 11C EXTENDED dB(A) WEIGHTING CURVE

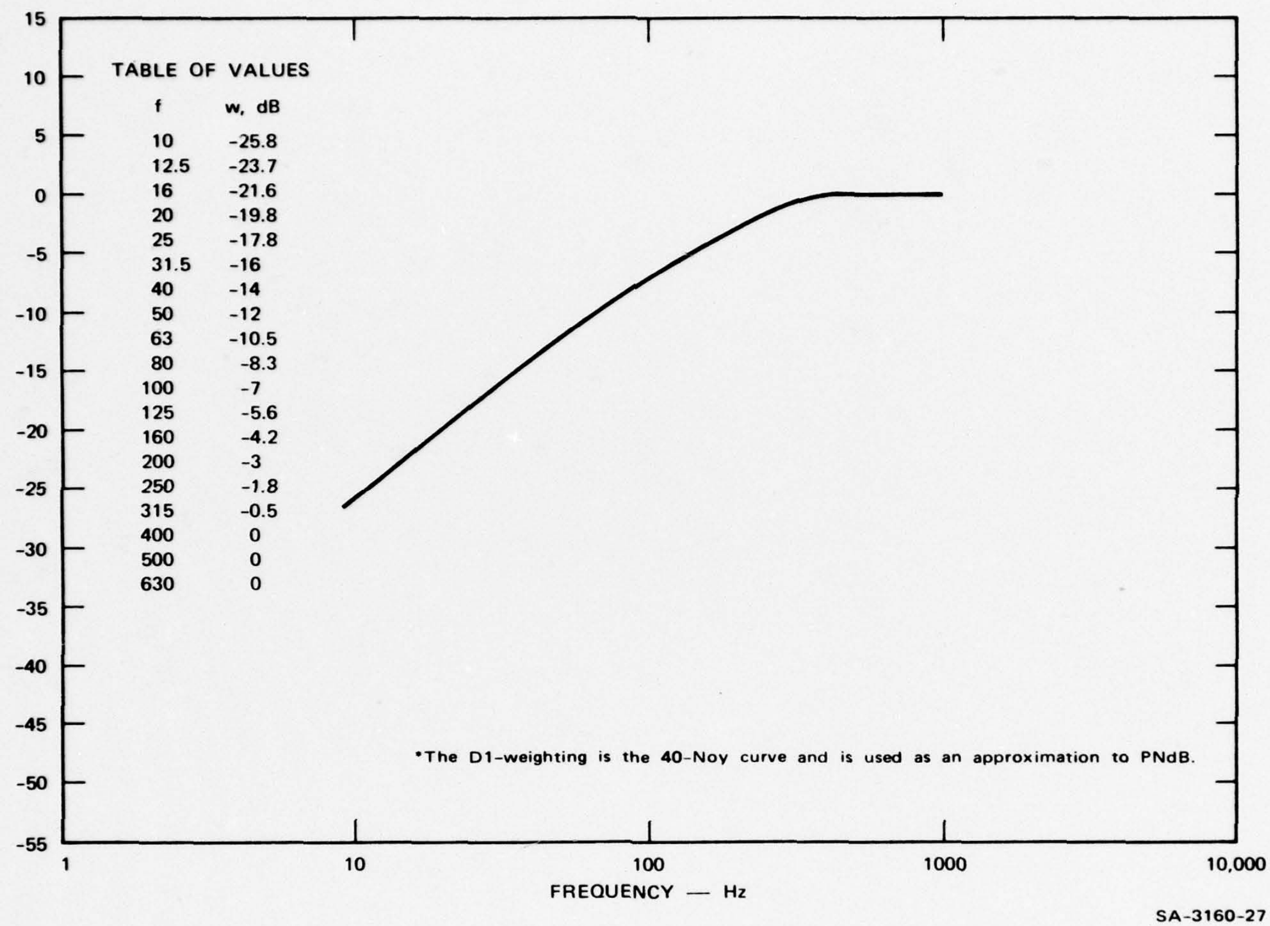

TABLE OF VALUES

f	w, dB
10	-25.8
12.5	-23.7
16	-21.6
20	-19.8
25	-17.8
31.5	-16
40	-14
50	-12
63	-10.5
80	-8.3
100	-7
125	-5.6
160	-4.2
200	-3
250	-1.8
315	-0.5
400	0
500	0
630	0

FIGURE 12C EXTENDED dB(D1)* WEIGHTING CURVE

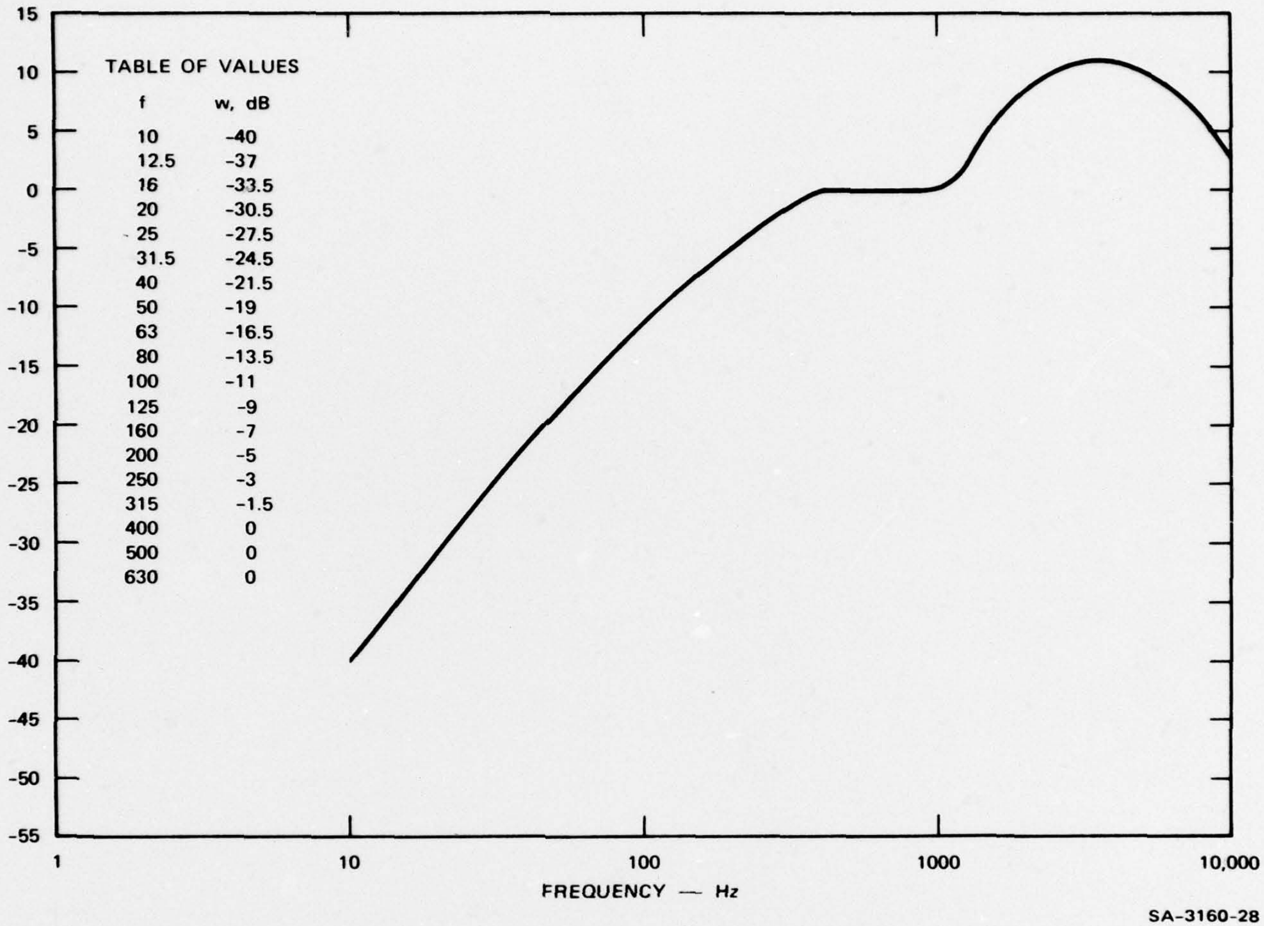

TABLE OF VALUES

f	w, dB
10	-40
12.5	-37
16	-33.5
20	-30.5
25	-27.5
31.5	-24.5
40	-21.5
50	-19
63	-16.5
80	-13.5
100	-11
125	-9
160	-7
200	-5
250	-3
315	-1.5
400	0
500	0
630	0

FIGURE 13C EXTENDED dB(D2) WEIGHTING CURVE